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16. ABSTRACT The report gives results of a laboratory evaluation of 'impinge-release' and 'fish-avoidance' concepts for protecting fish larvae at cooling water intakes. Impinge-release requires a vertical-traveling screen that limits impingement time to several minutes, the maximum time depending on the species to be protected. A stationary slotted screen in flowing water was used to evaluate the ability of fish to avoid entrapment. Both concepts showed high potential for protecting larvae as well as older life stages. Approach velocities = or < 30.5 cm/s did not affect survival. But at 61 cm/s, survival was usually significantly reduced, especially for impingements over 2 minutes. Fish in a water-holding tray of a screen panel had higher survival than fish exposed to air on emergence of the panel from water. Low pressure sprays for rinsing fish into and from the tray, followed by spilling the fish into a return trough, did not significantly reduce survival. The large range in swimming ability, size, and behavior among species gave large differences in their avoidance response. Adequate protection for small larvae may require 0.5-mm slots and through-screen (slot) velocity = or < 7.5 cm/s. Large larvae (> 10 mm) can avoid screens with 2-mm slots and a 7.5-cm/s slot velocity. Except for channel catfish, larvae avoidance of the slotted screen was higher during daylight.

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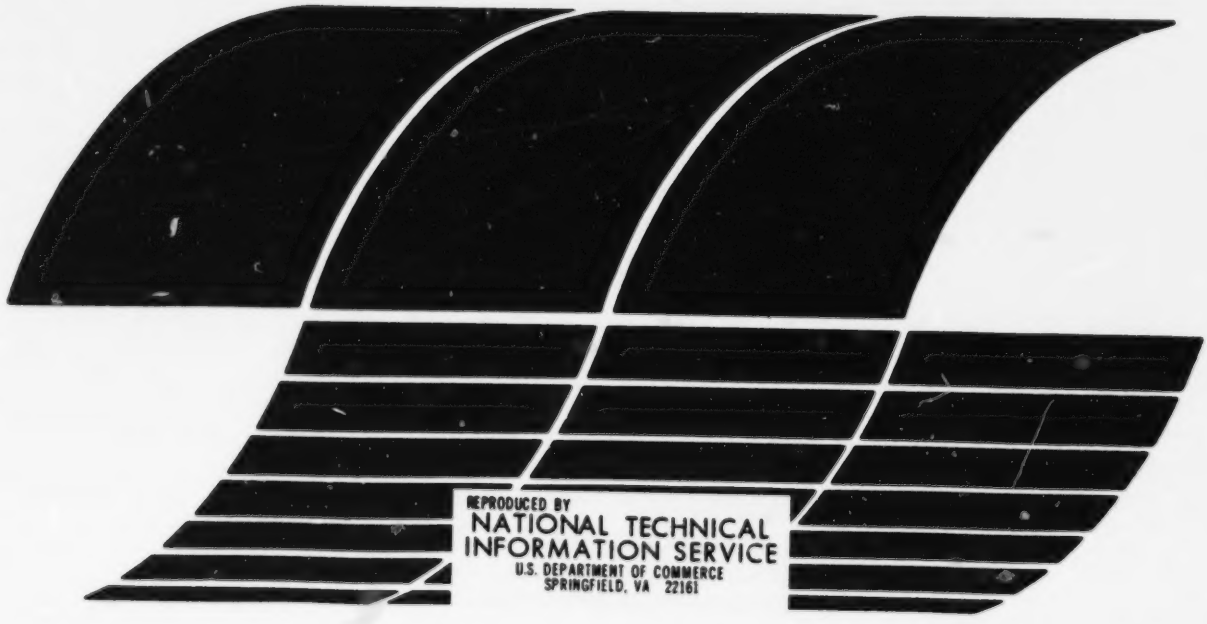

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ABSTRACT

Laboratory studies were conducted to evaluate two screening concepts for protecting larval fish at water intakes. Initial experiments with the "impinge-release" concept were designed to evaluate several variables affecting percentage retention and survival of larvae impinged for short periods of time on small-opening continuous traveling screens. These variables included species, screen opening size, approach water velocity, and impingement duration.

Subsequent experiments with this concept were designed to evaluate several fish handling components of a proposed vertical traveling fine-mesh screen, the purpose of which was to identify and modify, as necessary, any components of the screen or operating scheme that likely would result in high fish mortality. These components included impingement duration, exposure of the larvae to a "dry" screen as the screen panel traveled from the surface of the water to the top or spilling position, spilling of the larvae into a fish return trough, approach water velocity, sprays, and screen panel shape. Seventeen species of larvae representing a wide range in hardiness were used to evaluate this concept.

Investigations on a second concept ("fish avoidance") were designed to evaluate the ability of larval fish to avoid being entrained through and impinged against a stationary intake screen featuring low inlet velocities and narrow slotted openings. Experimental variables included velocity through the slot, screen slot orientation (perpendicular vs parallel) to flow, illumination condition (day vs night), screen slot width, a bottom refuge, fish age, and screen length. Twelve species of larval fish were used to evaluate this concept in a flowing water environment.

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SECTION 1

INTRODUCTION

In recent years increased attention has been directed at fish protection in the design and location of power plant intake structures especially since the enactment of Public Law 92-500 and the 1972 amendments which, under section 316(b), provide for "best technology available for minimizing adverse environmental impact."

An important consideration in the evaluation of cooling water intake screen systems as a mitigative device is the smallest fish that these devices and designs are capable of protecting.

Conventional traveling screen designs have effectively divided the fish community into two sizes: those that are retained by a standard 9.5 mm (3/8") mesh screen (impinged) and those that pass through the 9.5 mm screen (entrained). In the past, efforts were focused on ways to reduce impingement at existing plants while entrainment was largely neglected. TVA and EPA, as well as other organizations, have directed research efforts toward reducing impingement and entrainment mortality through improved screening technology.

A review of available literature identified two screening concepts with potential for reducing entrainment and impingement. This report details laboratory investigations on these concepts, the impinge-release concept and the fish avoidance concept.

Impinge Release Concept

In this concept, larval fish are retained in front of the intake structure by one or more continuously traveling fine-mesh screens. After impingement on the screen for a short time, the fish are released into a bypass or return trough and returned to the source water body.

Figure 1 illustrates three types of impinge-release systems that are currently available or are being considered for application to vertical travelling screens. The difference in fish handling among these screens is primarily in the method of transferring the fish from the screen panel to the fish return trough. In the single-entry, double-exit screen, fish are poured out of the panel directly into the return trough as the screen panel moves around the upper sprocket. In the other two screen types, the fish are either flushed out of the panel by a high volume flood of water or are spilled into a trough as the panel moves toward the back side of the sprocket. An additional impinge-release system, the horizontal traveling screen (Figure 2), rotates the screens horizontally beneath the water's surface releasing impinged material at the downstream end, eliminating air exposure of impinged organisms and screen panels.

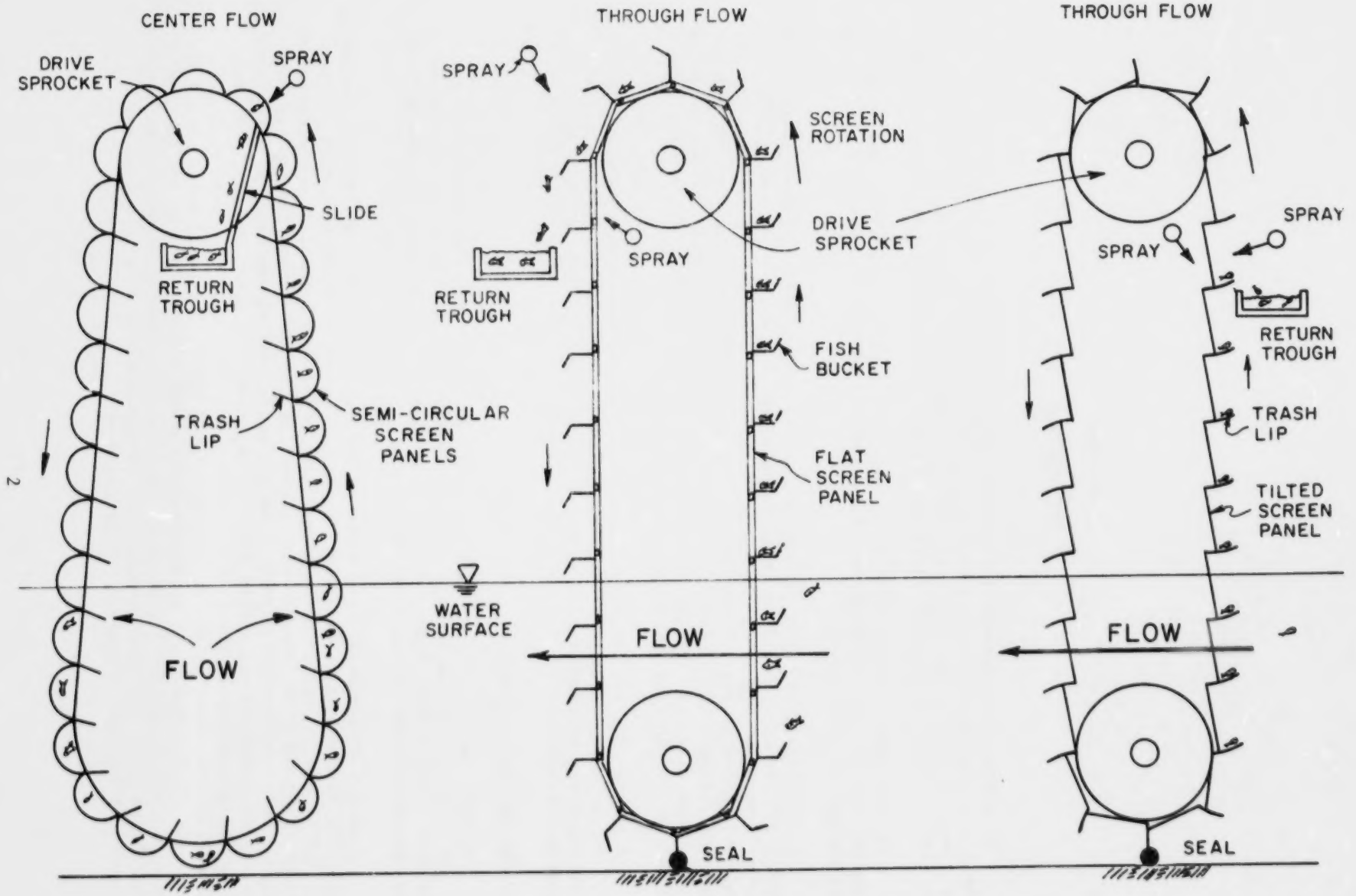


Figure 1. Three applications of the "impinge-release" method of fish protection using continuous traveling screens.

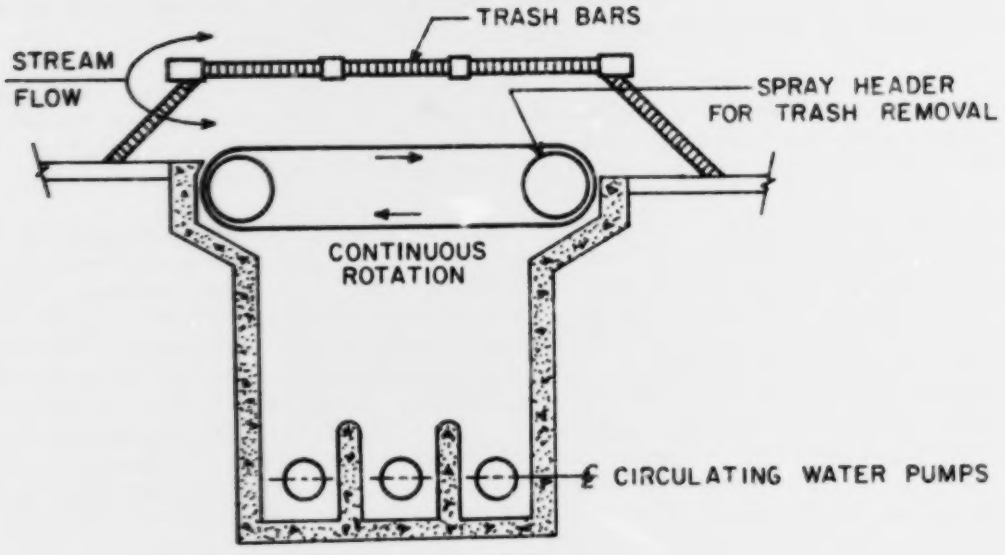


Figure 2. Horizontal traveling screen; schematic drawing.

Source: Document for Best Technology Available for the Location, Design, Construction and Capacity of of Cooling Water Intake Structures for Minimizing Adverse Environmental Impact. EPA 440/1-76/015-a, Washington, DC, April 1976.

Sazaki et al., (1972) conducted laboratory tests on the retention and impingement tolerance of larval and juvenile chinook salmon (Oncorhynchus tshawytscha), steelhead trout (Salmo gairdneri), striped bass (Morone saxatilis), and striped bass eggs. The purpose of the tests was to determine "if impingement is a feasible concept in screening" to protect the anadromous fishery resources at the 623 m^3/s (22,000 cfs) Peripheral Canal water diversion in California. They found that a screen with openings no greater than 0.4 mm was needed to retain all striped bass larvae, the smallest fish tested. Although survival of striped bass eggs and larvae was high under several test conditions, it was concluded that screening was not feasible for individual striped bass larvae less than 40 mm (1.6 in.) in length at velocities exceeding 18.3 cm/s (0.6 fps).

In another study, Prentice and Ossiander (1971) obtained essentially 100 percent retention and survival of 26 mm (1 in.) chinook salmon (Oncorhynchus tshawytscha) on a screen with 2.5 mm openings at approach velocities up to 30.5 cm/s (1 fps) and impingement durations up to 30 minutes.

In TVA's initial feasibility study conducted in 1976, (Appendix A), several variables which could influence the success of the impinge-release concept were identified. These variables included the size of screen opening, the water velocity in front of the screen (approach velocity), and the length of time that the fish were retained on the screens (impingement duration). The hypothesis was that retention on a fine-mesh screen would depend primarily on some body dimensional feature of the fish and secondarily on approach velocity and/or impingement duration. A second hypothesis was that survival of these retained larval fish would be primarily dependent on impingement duration and secondarily dependent on approach velocity and fish size. Finally, large interspecies differences were expected, especially in survival of the retained individuals. The results of these initial studies indicated:

1. It is feasible to retain larval fish with fine-mesh screens.

2. The most important experimental variable with respect to percent retention is mesh size.

3. A 0.5 mm screen opening retained 98 percent of the smallest larval fish tested.

4. Impingement durations up to four minutes resulted in 80-100 percent survival.

5. Low current velocities $\leq$30.5 cm/s (1.0 fps) through the screen provided the highest survival.

Based on these results, a second phase of the study was conducted during 1977-1979. The purpose of the second phase was to evaluate larval fish survival associated with all aspects of fish handling on a laboratory screen. These data will be used to optimize survival of fish by modifying any components of the screen which cause significant mortality to the larvae. This report describes the laboratory model test screen, experimental designs, results of tests, and identifies remaining areas of study that need to be addressed in order to develop a final prototype design.

Fish Avoidance Concept

This concept depends on the ability of the fish to swim away from the intake. Basic fish protection requirements of this concept, which enable larvae to swim away from the screen, include small openings and low water velocities through the screen. This concept is being evaluated for application to a stationary screen.

Larval fish just a few days old are capable of orienting to low water velocities (Tomljanovich et al., 1977). Sazaki et al. (unpublished report, California) tested swimming abilities of larval and juvenile chinook salmon, steelhead trout, and striped bass. They found that 90 percent of the 10-12 mm striped bass tested were able to maintain themselves in a current of 6.1 cm/s (0.2 fps) for six minutes while 90 percent of the 50 mm fish were able to maintain themselves in an 18.3 cm/s (0.6 fps) current for six minutes.

Several applications of the fish avoidance concept have been suggested for possible use at low-volume power plant intakes. Stober et al. (1974) conducted studies on the use of rapid sand filters for protecting larval and juvenile fish and large invertebrates from entrainment into power plant intakes. McSwain and Schmidt (1976) reported on the use of a gabion screen in combination with perforated pipes buried in river-run gravel to protect juvenile salmon in the Merced River in California. Water passes through the gravel and perforated pipes at velocities low enough to prevent fish entrapment. Richards and Hroncich (1976) reported the development of a perforated pipe intake for the protection of fish at a 1.58 m^3/s (55.7 cfs) water pumping station on the Columbia River. In this design, the pipes rested on supports above the river bed rather than in the substrate. The perforations were 9.5 mm in diameter and the velocity through them was 15.2 cm/s (0.5 fps). The approach velocity 9.5 mm from the screen was reduced to 6 cm/s (0.2 fps).

The design of a fish avoidance screen is necessarily dictated by the swimming ability and behavior of the species of larval fish that are to be protected, the site specific physical characteristics of the intake location, and requirements for plant water flow. If an intake based on this concept is successful in protecting larval fish, it will also provide protection for juvenile and adult fish which have greater swimming ability.

The fish avoidance study was designed to estimate the ability of several species of larval fish to avoid impingement against and entrainment through a fish avoidance screen in flowing water. This concept also may have potential for use in nonflowing situations. The stationary test screen used was made of slotted stainless steel with wedge-shape wire (Smith 1977).

The safe transport of larval fish past such an intake was expected to be influenced by the following variables:

1. Screen dimensions and shape.
2. Width of screen slot opening.
3. Combination of slot (through-screen) and bypass water velocities.
4. Proportion of total flow withdrawn through the intake screen.

5. Orientation of the screen with respect to the river flow.

6. Differences in behavior, size, and swimming ability among different larval fish species.

As in the impinge-release concept, the fish avoidance project was conducted in two phases, an initial feasibility study (Appendix B) and a phase two effort.

The basic analysis of the first phase of the study compared proportion of total number of fish bypassed (avoidance) with proportion of total flow bypassed. The hypothesis tested was that the larvae were essentially passive with respect to swimming ability and if homogeneously distributed in the approach flow, they would be entrained and bypassed in the same proportions as the respective bypassed and entrained portions of the flow. In these tests fish were exposed to a 1.2-m-long section of screen. The above hypothesis was rejected; all species except very young muskellunge had higher proportion bypass values than corresponding flow bypass values under most experimental conditions. These results suggested that a large proportion of larval fish and probably all juvenile-adult fish that would be exposed to this type screen could avoid entrapment.

In the second phase additional laboratory tests were conducted in 1978 to more fully evaluate the "fish avoidance" concept. The primary objective was to evaluate the effect of several experimental variables on avoidance of entrapment, including illumination, slot orientation, through-screen velocity, slot width, fish age, a bottom refuge, and screen length.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

Impinge-Release Concept

The objective of this study was to provide the necessary information to evaluate fish handling components of a prototype fine-mesh intake screen using the impinge-release concept. The initial results showed that the amount of modification needed to optimize survival will depend largely on the species and life stages to be protected.

A large range in survival among species suggested that a similar pattern would be found in the natural environment using a prototype screen. Consequently, an average survival rate for larval fish would not be meaningful. Much of the range in survival among species was related to size differences for a given age among species.

If a species that has relatively large larvae is to be protected, little or no modification to the basic fine-mesh screen may be needed. For this group of larvae, 90 to 100 percent 24-hour survival after four minutes "impingement plus spilling into a return trough" can be expected. However, for protection of small, fragile larvae, such as striped bass, considerable modification may be required to provide optimum protection. To date, tests discussed here have shown only limited success in protecting the very fragile species using the impinge-release screening concept. However, high control mortality in tests with these species suggested that the laboratory studies have not adequately described the effect of the screen on survival.

In the impinge-release tests, impingement had the greatest effect on survival, followed by exposure to air as the larvae traveled in a "dry" screen to the spilling position. Survival of larvae after spilling into the return trough was not consistent between two types of tests. Additional studies need to be conducted on this aspects of the impinge-release system.

For species of intermediate hardiness, (redbreast sunfish, largemouth bass, bigmouth buffalo, walleye) it appeared that providing a water trough to the screen panel, limiting the impingement time to four minutes or less, and providing low pressure sprays for fish removal would significantly increase survival.

For five species tested (smallmouth and largemouth bass, river carpsucker, black buffalo, walleye) approach water velocities of 30.5 cm/s (1.0 fps) or less did not significantly affect survival. Velocities equal to or greater than 61 cm/s (2.0 fps), especially when impingement duration exceed two minutes, can be expected to reduce survival for most species of similar hardiness to those tested. Most larvae adhered to the screen panel fabric when the panel was raised

from the water. An emergent spray installed near the water surface rinsed the larvae into the water-holding tray at the bottom of each screen panel. A low pressure spray of sufficient volume to gently rinse the fabric consistently transferred both larvae and weeds into the tray. It was apparent from observation that neither this spray nor the overhead low volume spray, used to ensure that all larvae spill into the fish return trough, would be an important source of mortality.

Small larvae of some species which have distinct filiform shaped bodies will become entrapped in screen openings of 0.5 mm square mesh. A low pressure emergent spray would be ineffective in rinsing them out of the fabric. Additional testing with smaller opening screens is needed to determine the maximum screen opening that could be used to prevent entrapment for these fish.

Comparisons of screen panel shapes suggested that higher survival will be obtained if the larvae are impinged against the fabric (rather than being allowed to reside in an eddy produced by a high tray lip). Only a few centimeters of water depth are required for larvae and juvenile fish to reside in during screen travel.

Self-cleaning angled screens were not found to consistently rinse the larvae into the tray upon screen panel emergence and sometimes resulted in lower survival than conventional screens. However, these screens were not tested extensively and a more indepth evaluation of unique screen panel shapes may be warranted.

To adequately describe the effect of the impinge-release process on the larvae, it may be necessary to more fully evaluate the shock response observed for several species. It would appear that a recovery time exceeding several minutes would impair the ultimate survival of stunned fish discharged back to the source water body. An intermediate holding facility may need to be considered in some cases to allow the fish to recover prior to returning them to the source water body.

Fish Avoidance Concept

The results of this study indicated that a "fish avoidance" water intake screen has high potential for protecting a large percentage of fish larvae which could potentially be entrapped. All variables that were tested represent important design parameters for a prototype screen. In addition, large differences in avoidance among species and ages dictate the need to consider species and sizes of fish available at a particular site when designing an intake of this type.

The tests indicated that to provide optimum protection for very small larvae (<6.0 mm total length) a screen slot width of 0.5 mm and a slot velocity no greater than 7.5 cm/s may be required.

Use of a 1.0 mm slot and sufficiently low through-screen velocity would probably enable all larvae over 10 mm total length to avoid entrapment. For some species a through-screen velocity as high as 15.0 cm/s would not appreciably reduce avoidance, but for others it would be necessary to limit slot velocity to 7.5 cm/s (0.25 fps). Several species between 7 to 10 mm total length would probably avoid a screen of 1.0 mm slot width if through-screen velocity was limited to 7.5 cm/s. For some species slot orientation and lighting may need to be considered in order to optimize avoidance.

A screen with 2.0 mm wide slots could be used to effectively protect most species of larvae which exceed 10 mm length. With this slot size, use of low slot velocity (7.5 cm/s) and orienting the slots perpendicular to flow direction may be required to optimize avoidance for most species. Higher slot velocity could be used and still provide adequate protection for juvenile and larger fish during periods when larvae are not present.

Inclusion of a bypass area located below the screen (in the case of a vertical flat screen oriented parallel to flow direction) probably would increase avoidance for nearly all species.

A prototype screen should also be designed to provide sufficient velocity at the downstream end of the intake to prevent reversal of stream flow. This provision will preclude problems associated with reexposure of the larvae to the screen by ensuring that once bypassed they will be carried downstream away from the intake.

Because of the potentially significant effect of so many design parameters, it is obvious that a generalized optimum screen cannot be proposed. The results of this study will be useful for site specific designs after an indepth evaluation has been made of the fish species present and other biological and nonbiological considerations have been assessed.

SECTION 3

IMPINGE-RELEASE CONCEPT

MATERIALS AND METHODS

Summary of Initial Laboratory Study

A complete discussion of the test facility, test procedures, experimental variables, results, and conclusions is presented in Appendix A.

Results of the first year of study suggested that most species of larvae could be retained on a screen having 0.5 mm openings and that sufficiently high survival could be obtained for many species if impingement duration was limited to four minutes or less. There was no basis on which to estimate the effect on survival of the remaining stresses associated with the impinge-release process. Thus, a second phase of laboratory testing was begun in spring 1977, the purpose of which was to evaluate all of the fish handling components of a single-entry, double-exit vertical travelling screen.

This phase of the study was conducted over a period of three years during the several months when larval fish were available. During the first year of this phase it became apparent that abnormally high ambient water temperatures of the laboratory water may have adversely affected survival. During the second year of this phase, a chilling unit was installed which enabled matching the flume temperature to holding water temperature.

Test Facility

In early 1977, construction was started on the laboratory test screen. Since the test facility was not completed until well into the larval fish season, only four species were tested in 1977. Provisions were made for installing a refrigeration unit capable of regulating flume water temperatures. Installation of this unit was completed midway into the 1978 testing program.

The test screen was installed in a 15.2 m long by 1.2 to 2.4 m wide by 1.2 m deep flume (Figure 3). Although the test facility did not resemble the prototype in appearance, each prototype fish handling component to which the fish would be exposed was represented. A rail hoist rather than a sprocket similar to that found in the prototype was used to mount two screen panels, each 53 cm high and 1.2 m wide. The rail hoist provided greater working space for the experimenters without altering the actual trajectory of screen travel. During the first two years of Phase II testing the top panel was flat and the bottom panel was semi-circular (Figure 4). Each screen panel was divided in half by a vertical baffle. On the right half of each panel, the bottom few centimeters of screen fabric were sealed with epoxy paint (Figure 4). This created the "wet" screens: as the screen

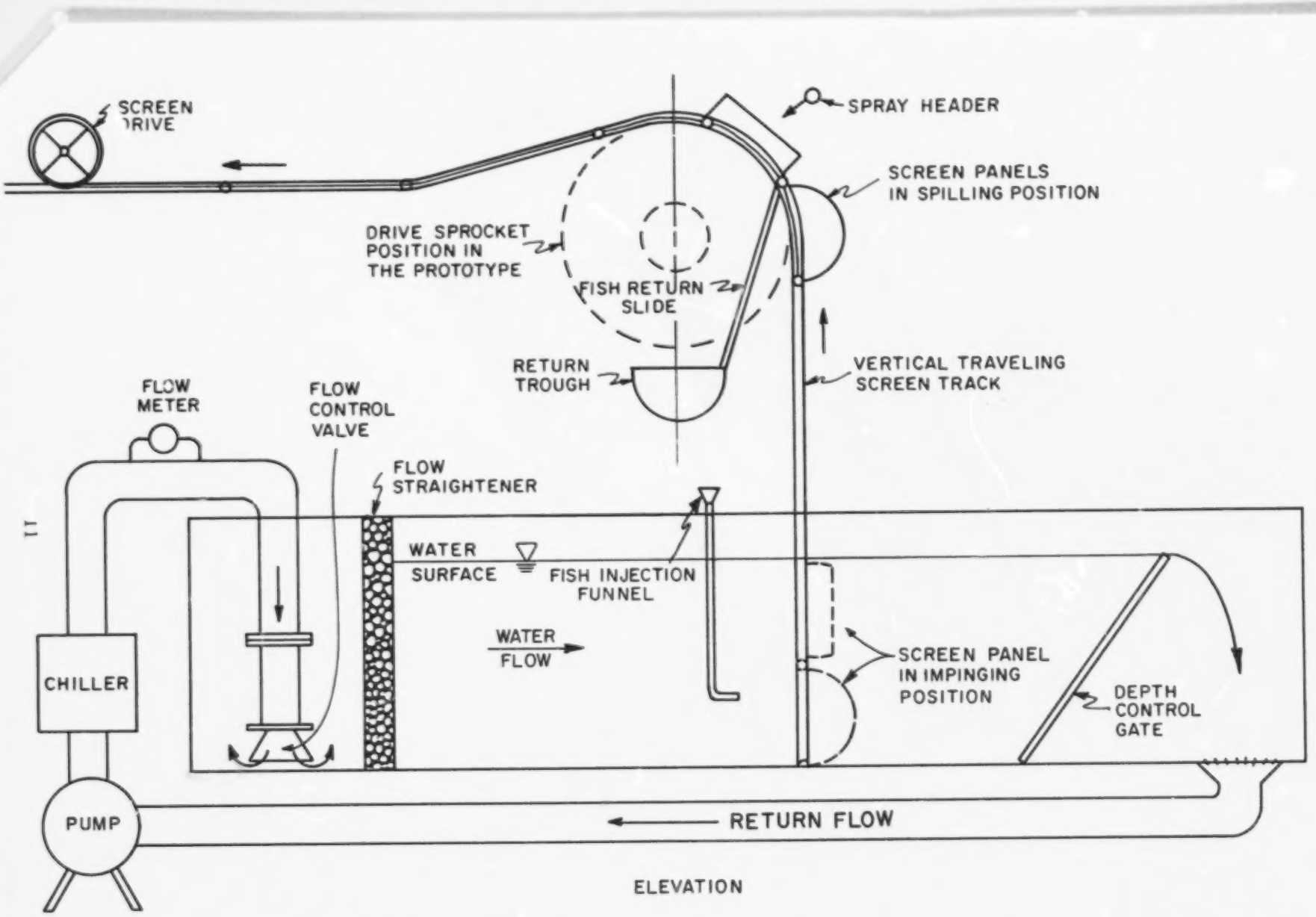


Figure 3. Laboratory test facility used to evaluate the effect of several fish handling components of a continuously traveling fine mesh screen on larval fish survival.

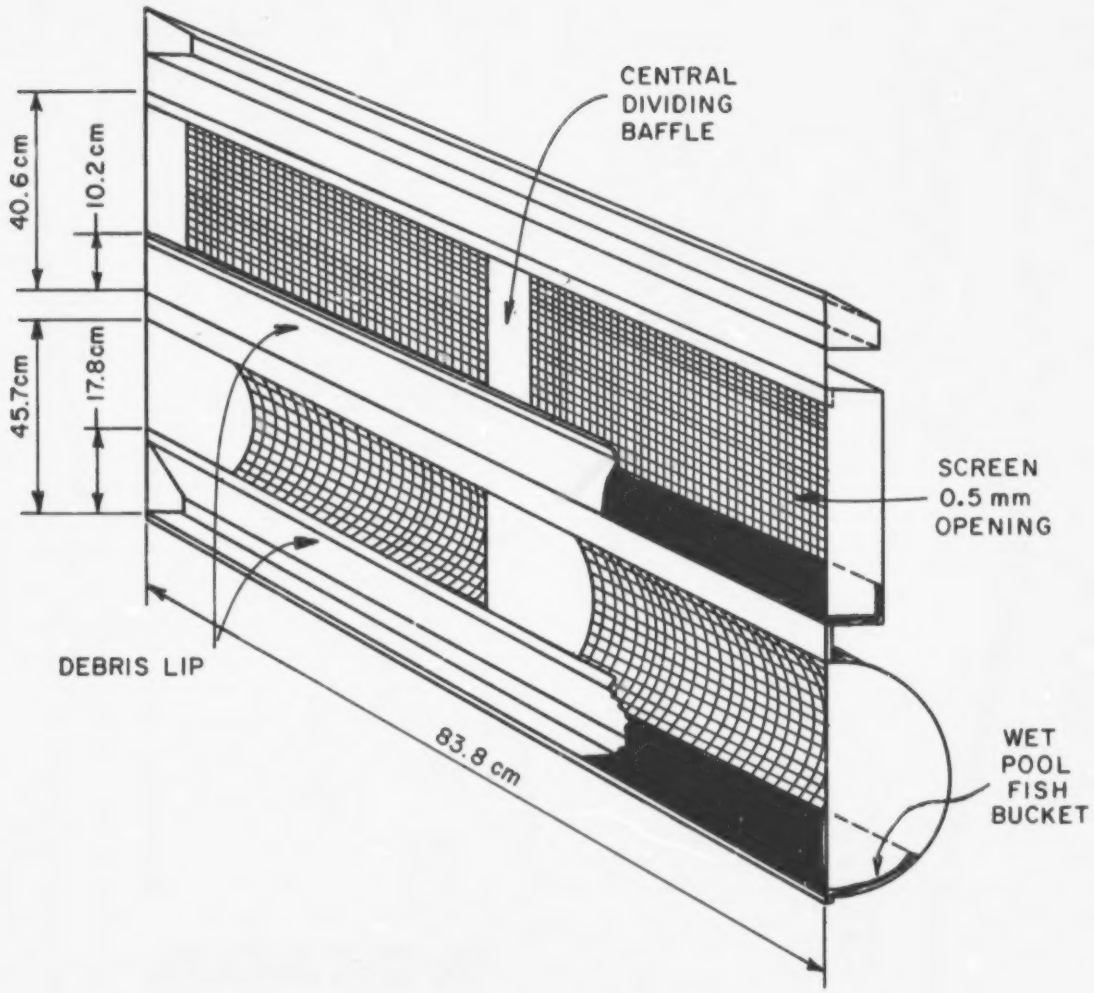


Figure 4. Two screen panels that were used to evaluate the survival of larval fish exposed to several fish handling components of a prototype fine mesh traveling screen.

panels were raised out of the flume, a shallow pool of water was retained in the "wet" portion of each panel. The unsealed left side of each panel ("dry" screen) did not hold a pool of water. The screen dimensions (except width), overhead sprocket diameter (in this case rail curvature), and the length of the fish slide, which extended from the spill position to the fish return trough, were prototype size. During the third year of testing, additional panel shapes were tested.

During Phase II testing, several separate experiments were conducted. During the first two years, tests were limited to the first experiment which are labeled the baseline tests. During the third year, three additional species were tested under these same conditions, and several other experiments were conducted.

Description of Experiments

1. Evaluation of Effect of Impingement Duration, Air Exposure During Screen Panel Emergence and Travel to Spilling Position, and Spilling into Return Trough. This baseline experiment evaluated survival among levels of exposure to these three major fish handling components of the impinge-release process.

A complete test series of each impingement duration and species included: (1) impingement alone, (2) impingement plus spilling into return trough without air exposure (fish were carried to spill position in the "wet" screen), (3) impingement plus one minute air exposure, (4) impingement plus one minute air exposure plus spilling into return trough, (5) impingement plus three minutes air exposure, and (6) impingement plus three minutes air exposure plus spilling into return trough. "Impingement alone" represented the lowest level of exposure to the test facility whereas "impingement plus spilling from the wet screen into the fish return trough" (no air exposure) represented the lowest level of exposure that can be designed for a prototype vertical traveling screen (excluding sprays and the ride back to the river via the fish return trough). The remaining categories of testing represent kinds of exposure the fish would experience on an unmodified screen panel. It was hypothesized that as the exposure increased, survival would decrease.

Experimental Variables

Screen panel shape	- flat semicylindrical	
Screen opening	- 0.5 mm	
Approach water velocity	- 15.0-22.9 cm/s (0.5-.75 fps)	
Screen travel speed	- 6.4 m/min (21 fpm)	
Impingement duration	- 1.0, 2.0, 4.0 min	
Air exposure duration	- 1.0, 3.0 min	
Fish species	- Paddlefish	(Polyodon spathula)
	Northern pike	(Esox lucius)
	River carpsucker	(Carpiodes carpio)
	Quillback	(C. cyprinus)
	White sucker	(Catostomus commersoni)
	Channel catfish	(Ictalurus punctatus)
	Smallmouth buffalo	(Ictiobus bubalus)
	Bigmouth buffalo	(I. cyprinellus)
	Black buffalo	(Ictiobus niger)
	Striped bass	(Morone saxatilis)
	Striped bass x white bass	(Morone hybrid)

Redbreast sunfish	(Lepomis auritus)
Largemouth bass	(Micropterus salmoides)
Walleye	(Stizostedion vitreum)

A three-replicate design was employed for all tests. In each test a sample of fish was removed from the transfer container and placed in a beaker. These test fish were carefully examined and any dead fish removed before testing. The live fish were introduced into the current directly in front of the test screen via an L-shaped 25 mm diameter plastic pipe (Figure 3). In the "impingement only" tests, after one, two, or four minutes impingement, the test screen panel was raised, leaving only the bottom few centimeters on the panel immersed. As the upper portion of the screen panel emerged from the water, any impinged fish which adhered to the screen were gently splashed into the water at the bottom of the panel. These fish were then siphoned into a styrofoam cooler. Dead individuals were removed and counted, and the live fish were left in the cooler for 24 hours to assess delayed mortality. This part of the test series (impingement only) provided a means for determining the effect of additional fish handling components.

In the "impingement plus air exposure" tests, the screen was raised completely out of the water following the impingement period, and the impinged fish were exposed to the air for one or three minutes to simulate travel time of an unmodified prototype screen panel from the water surface to the top of the screen structure. At screen speeds of 4.2 and 8.5 m/min (14 and 28 fpm), a three-minute air exposure represents a range of total distance from water surface to the top of the screen structure of 12.6 to 25.5 m (41 to 84 ft). Immediately following the air exposure period, the bottom portion of the screen panel was lowered into the flume to facilitate siphoning the fish into coolers. Dead fish were immediately removed and counted, and live fish were held 24 hours for assessment of delayed mortality.

The next test of the series consisted of impingement, followed by exposure to air (one or three minutes), followed by spilling a distance of approximately 1 m into a return trough. As the screen panel reached the spill position, a gentle spray directed from behind the screen was used to flush all fish from the panel. The fish were siphoned from the trough into a styrofoam container and treated as described for earlier tests.

In the final test of the series, the fish were impinged, carried to the spill position in the pool of water in the "wet" screen, spilled into the return trough, and removed and treated as described for the other tests.

2. Evaluation of Effect of Approach Water Velocity on mortality of larvae which were exposed to impingement and spraying followed by spilling into the fish return trough. All species were tested using the flat vertical screen. Tests with largemouth bass also included a curved panel.

The velocities and impingement durations tested for each species are listed below:

Species	Approach Water Velocity in cm/s	Impingement Duration in min.
Black buffalo	15.0 (.5 fps), 30.5 (1 fps)	1, 2, 4
Walleye	15.0 (.5 fps), 30.5 (1 fps)	1, 2, 4
River carpsucker	15.0 (.5 fps), 30.5 (1 fps), 61 (2 fps)	2, 4, 8
Largemouth bass	23.0 (.75 fps), 46 (1.5 fps)	4, 8
Smallmouth bass	30.5 (1 fps), 61 (2 fps)	4, 8

3. Evaluation of Sprays. Several aspects of spraying were evaluated:

   a. Effectiveness in transferring fish from position of adherence on screen mesh to water in screen panel tray.

   b. Effectiveness in transferring fish from screen panel tray to return trough.

   c. Effect on survival of larvae impinged and spilled into a return trough. The test facility was designed to simulate the collection and removal process of a single-entry, double-exit vertical traveling screen. With this type screen the debris, water, and fish spill over the tray lip rather than over the screen itself as in the case of conventional through-screens (Figure 1). Therefore the fish are spilled directly into the fish return system without being exposed to the air or screen surface. The screen panel tray begins to spill when it starts to travel around the top sprocket. Length of time required for the panel to completely spill is dependent on the design of the tray, diameter of the sprocket and speed of screen travel. Most screen panel contents empty before reaching the sprocket axle. This is recommended to minimize stress to the fish during the process of returning them to the source water body via the return system.

Two rows of spray nozzles were installed to enhance the safe transport of larvae through the screening process (Figure 3). To facilitate rinsing any impinged fish into the water holding portion of the screen panel, one row of spray nozzles was mounted behind the screen on a 5 cm diameter steel pipe manifold located approximately 40 cm above the water surface. This emergent spray consisted of six deflector type flat spray nozzles mounted on 14 cm centers. This spray could be moved from 5 to 30 cm from the screen panel and could be rotated to change the angle at which the spray hit the screen. Flow rate through this spray ranged from approximately 0.9 to 1.3 ℓ/s (14 to 20 gpm).

A second row of sprays was installed to assist in removing fish and debris from the screen panel in the spill position. This low pressure spray initially consisted of six full cone center jet nozzles mounted on a 7.6 cm (3 in.) diameter PVC pipe manifold. Later, five additional nozzles were installed to achieve closer spacing and more complete coverage of the screen panel. These 11 nozzles were mounted on 7.6 cm centers and were positioned approximately 40 cm above the screen panel roller guide. Total flow rates ranged from approximately 1.0 to 2.3 ℓ/s (15.5 to 36.5 gpm).

Evaluation of the requirements and effects of the overhead spray for assisting in spilling fish into the return trough was mostly based on observations and

trial and error adjustments of the spray angle, pressure and distance from the screen panel. The number of fish remaining in the panel tray was recorded for four species during tests in which 11 nozzles were installed.

Variables included in tests for survival were spray volume, spray angle to screen, cleanness of screen (clean vs clogged), approach water velocity, screen panel shape, impingement duration, and screen travel speed. Species tested included black buffalo, striped bass, walleye, striped x white bass, quillback, river carpsucker, largemouth bass, smallmouth bass, and bluegill.

4. Evaluation of Screen Panel Design. Several screen panels were tested to determine the effect of panel shape on (1) adherence of fish to screen during emergence, (2) spilling, and (3) mortality of the larvae.

Screen panel shapes included flat vertical (Figure 4), flat inclined 30° from vertical, flat inclined 60° from vertical, curved with standard lip (Figure 4), curved with high lip, and curved with low lip. All panels were equipped with water holding trays. Results presented are based on tests using clean screens.

Inclined flat screens were tested primarily to determine if the fish would avoid adhering to the screen as they emerged from the water. If this were the case there would be no need for an emergent spray. The possibility also existed that the larvae could avoid impingement by moving down the angled screen and getting into the screen panel tray.

The purpose of testing high and low lip curved screens was to compare the effect on survival of an eddy produced behind both high and standard lip screens with no eddy in the low lip screen panel. It was noted in previous testing with the standard lip curved screen that some species were able to avoid impingement by staying in the eddy produced between the lip and the screen. Species tested included river carpsucker, striped x white bass, striped bass, black buffalo, bigmouth buffalo, smallmouth bass, largemouth bass, and walleye.

Acquisition and Pretest Holding of Test Fish

Most species of test fish were obtained as larvae from State or Federal fish hatcheries. A few species were cultured in-house. Details of culture methods and success are found in Yeager (1979).

Just prior to testing, the fish were transferred in an 11.4ℓ plastic pail from the holding tank to the test facility. Prior to installation of the refrigeration unit, test fish were acclimated to the higher flume water temperature by submerging the holding container in the flume and slowly adding flume water to the holding container until the temperature difference was within 1 C. After installation of the refrigeration unit, flume water temperature was adjusted to within ± 1 C of holding water temperatures prior to testing.

Controls

Several control groups were established during each day of testing. Approximately 25 to 200 fish (depending on the numbers of fish available and hardiness of species) were removed from the transfer container and placed in a styrofoam cooler containing water from the test flume. Survival of these control groups at the end of 24 hours was used to adjust 24-hour survival of four species of test fish (adjustment formula presented in Appendix C).

Numerical Analysis

In all cases, survival of test groups was calculated as a percentage. To satisfy the assumption of normality for parametric analyses, these data were transformed by an arcsin function (Sokal and Rolfe 1969). For selected species, 24-hour survival was adjusted for the observed control survival. The effects of the experimental variables were analyzed using multifactor analysis of variance (ANOVA) techniques available with the Statistical Analysis System (SAS), General Linear models procedure (Barr et al. 1976). Duncan's Multiple Range tests, which were also available with the SAS procedures, were used to compare mean survival among levels of each significant effect.

RESULTS AND DISCUSSION

Sixteen species from seven taxonomic families were used to evaluate the laboratory model fine-mesh traveling screen during the second phase of testing. The larvae ranged in age from 2 to 16 days and average total length from 5.0 mm to 16.0 mm (Table 1). These fish ranged in hardiness from very hardy to very fragile and probably closely approximate the range in hardiness of fish of these ages that would be found in the natural environment.

Water Quality

Dissolved oxygen was measured regularly throughout the testing period and ranged between 80 and 95 percent of saturation. Before the refrigeration unit was installed, holding water temperatures were always lower than corresponding flume water temperatures. This temperature difference ranged among six species from 1 C for striped bass to 8.5 C for largemouth bass. For two fragile species, striped bass hybrid and walleye, flume water temperature exceeded holding temperature by 5 to 6 C and 5 to 7 C, respectively, during a three-day test period for each species. Holding temperatures during this period ranged from 15.0 C to 21.0 C compared to 21.5 to 24.4 C for flume temperatures.

Other selected water quality parameters were measured twice in 1978 and once during 1979, (Table 2). None of these results suggested that poor water quality (apart from water temperature) contributed to any of the mortality observed.

Control Survival

Initial and 24-hour control survival was usually high for most species (Table 3). Average initial survival, which was evaluated for the 1979 tests only, was at least 92 percent for all species except striped x white bass and bluegill. Twelve species experienced mean 24-hour survival of at least 95 percent for one or more age groups or test years.

Striped x white bass hybrid tested in 1979 arrived in poor condition (evidenced by about 50 percent mortality) which was reflected in the comparatively lower initial survival experienced for the hybrid (58 percent) than for the striped bass (92 percent). Bluegill larvae showed 24-hour control survival equal to or greater than 75 percent. However, this species showed essentially 100 percent initial mortality after being tested under the least stressful conditions.

TABLE 1. AVERAGE SIZES AND AGES OF FISH LARVAE USED TO EVALUATE A LABORATORY MODEL FINE-MESH TRAVELING SCREEN. AVERAGE TOTAL LENGTHS WERE DETERMINED FROM MEASUREMENTS OF INDIVIDUALS FROM SELECTED CONTROL AND TEST GROUPS. THE LOCATION FROM WHICH SOME SPECIES WERE OBTAINED IS INDICATED IN PARENTHESES.

Species	Test Year	Age (days)	Mean total Length (mm)	Range (mm)
Paddlefish	1978	3	14.0	13.0-15.0
Northern pike	1978	6	13.5	13.0-14.5
River carpsucker	1979	3	6.6	6.0-7.0
		4	7.1	6.0-8.0
		5	7.4	7.0-8.0
		6	7.4	6.0-8.0
Quillback	1979	4	9.3	8.5-10.0
White sucker	1978	4	13.5	12.0-15.0
Smallmouth buffalo	1979	4	8.3	8.0-8.5
Bigmouth buffalo	1978	8		
Bigmouth buffalo	1979	7	7.3	6.5-8.0
Black buffalo	1979	5	7.1	6.0-8.0
Channel catfish	1977	4	12.2	10.5-14.0
Striped bass	1978			
(Georgia)		3	6.0	4.5-6.5
(New York)		6	6.0	6.0-6.0
(New York)		16	7.0	6.0-8.0
(Tennessee)	1979	5	5.4	5.0-5.5
(Tennessee)		6	5.3	5.0-6.0
Striped x white bass	1978	6	5.0	4.5-6.0
Striped x white bass	1978	15	6.0	4.0-7.5
		16	6.5	5.5-8.0
	1979	17	6.5	6.0-7.0
Redbreast sunfish	1978	5	7.6	6.0-9.0
		6	7.9	6.0-9.0
		19	10.8	10.0-12.0
Bluegill	1979	ca 8	6.0	5.0-7.0
		ca 13	5.8	4.5-6.5
		ca 16	6.6	6.0-7.5

TABLE 1. (continued)

Species	Test Year	Age (days)	Mean total Length (mm)	Range (mm)
Smallmouth bass	1979	unknown	10.2	9.5-11.0
Largemouth bass	1978	5	7.0	6.0-7.5
	1979	unknown	6.0	5.5-6.0
Walleye	1978			
(Wisconsin)		4	9.0	8.0-10.0
(Minnesota)		4	9.0	5.5-10.5
		5	9.5	8.0-10.0
		6	9.5	8.0-10.0
		10	10.6	9.0-14.0
(Wisconsin)	1979	2	8.0	7.0-8.5
		3	8.4	8.0-9.0
(Minnesota-Duluth)		4	9.0	8.5-9.5
(Minnesota-St. Paul)		unknown	9.2	8.0-10.0

TABLE 2. RESULTS OF ANALYSES OF SELECTED WATER QUALITY PARAMETERS FOR WATER USED IN TESTS OF A LABORATORY MODEL FINE-MESH TRAVELING SCREEN.

Parameter	Date		
	5-16-78	6-28-78	6-19-79
Temperature (C)	23.0	26.0	18.7
pH	8.0	7.9	7.9
Specific Conductance (umho/cm)	230	230	200
Total organic carbon (mg/ℓ)	1.3	1.4	2.0
BOD (mg/ℓ)	<1.0	<1.0	1.7
TKN (mg/ℓ)	0.19	0.06	0.08
NH_3-N (mg/ℓ)	0.01	0.04	0.04
NO_2+NO_3 (mg/ℓ)	0.34	0.38	0.62
Fe (mg/ℓ)	0.16	<0.05	<0.05
Cu (mg/ℓ)	0.05	0.07	0.01
Cr (mg/ℓ)	<0.005	<0.005	<0.005

TABLE 3. INITIAL AND 24-HOUR SURVIVAL OF CONTROL FISH USED IN LABORATORY TESTS IN 1978 AND 1979 ON A FINE-MESH TRAVELING SCREEN.

Species	Age (days)	Number of Replicates	Average Percentage Survival		
			Initial	24-hour	(range)
Paddlefish	3	1	NT[1]	96	
Northern pike	6	3	NT	98	
River carpsucker	3-16	18	100	99+	
Quillback	4	3	100	100	
White sucker	4	1	NT	99	
Smallmouth buffalo	4	8	99+	99	
Bigmouth buffalo (1978)	8	3	NT	59	(55-67)
Bigmouth buffalo (1979)	7	3	97	93	
Black buffalo	5-12	12	99+	99	
Channel catfish	4	1	NT	100	
Striped bass (1978)	3-16	10	NT	34	(0-95)
Striped bass (1979)	5-6	12	92	46	(29-75)
Striped x white bass (1978)	6-17	5	NT	48	(0-91)
Striped x white bass (1979)	17	2	58	41	(23-59)
Redbreast sunfish	5-19	8	NT	99	
Bluegill	8-16	7	84	80	(71-84)
Smallmouth bass	unknown	3	100	100	
Largemouth bass (1978)	5	3	NT	86	(71-100)
Largemouth bass (1979)	unknown	6	99+	99+	
Walleye (1978)					
(Wisconsin)	4	10	NT	55	(17-88)
(Minnesota)	4-10	13	NT	56	(14-78)
Walleye (1979)					
(Wisconsin)	2-3	12	99+	99	
(Duluth)	4	8	92	65	(45-89)
(St. Paul)	unknown	9	96	73	(63-83)

[1]Not tested

For a given species, test groups often contained several ages and individuals from different brood stocks (hatchery location and year class). Large within-species differences in average survival sometimes resulted between control groups. For example, mean 24-hour control survival between 8-day-old bigmouth buffalo tested in 1978 was 59 percent compared to 93 percent for 7-day-old individuals tested in 1979.

Walleye tested in 1978 were from two brood stocks (Minnesota and Wisconsin) but showed similar survival (55 and 56 percent). However, walleye tested in 1979 from these locations ranged from 65 to 99 percent, respectively. In this case the survival of 55 to 65 percent was associated with fish at least 4 days old, whereas the fish which show 99 percent 24-hour survival were 2 to 3 day-old fish. Decreased survival may have been associated with a critical life stage change such as absorption of the yolk sac and change to external feeding.

Evaluation of Effects of Impingement Durations, Air Exposures, and Spilling Into Return Trough

Thirteen species were used to evaluate the effect of these fish handling components. Seven species showed high survival under all test conditions and thus were not helpful in identifying any components of the screen that might need to be modified. The results of the 4 minute impingement series with these species are presented in Table 4. Smallmouth buffalo was also tested at 1 and 2 minutes impingement and showed 24-hour survival approaching 100 percent under all conditions. Similarly, river carpsucker were tested at 2 minutes impingement as well as 4 minutes and showed at least 91 percent 24-hour survival under all conditions.

Two species (striped bass and striped x white bass hybrid) showed highly variable and generally poor survival under all test conditions; thus, as above, a statistical analysis could not be used to identify problem areas in the screening process. Striped bass showed the lowest survival of the nine species tested. The first group of striped bass obtained in 1978 experienced nearly 100 percent mortality during the fourth night after hatching. A limited water quality analysis did not detect any problems with dissolved oxygen, pH, carbon dioxide, or temperature. Of 81 tests that were conducted with this species, mean initial survival was 19 percent, whereas mean 24-hour unadjusted survival was only 2 percent. Table 5 shows the survival results for each test condition. These values ranged from 6 to 29 percent for initial survival and zero to 7 percent for 24-hour survival. Survival of control fish (24-hour) for 10 samples averaged 34.3 percent and ranged from zero to 95 percent. A trend of decreasing survival with increasing exposure to test conditions was noted only for the two minute impingement series.

In 68 tests with striped bass x white bass hybrid, average initial survival was 64 percent, and average 24-hour survival was 15 percent. Because of low 24-hour survival for the two-minute impingement series, a complete four-minute impingement series was not conducted. Table 5 depicts average initial and 24-hour survival for each test condition. Average initial survival ranged from 21 percent for the highest level of exposure to 86 percent for the lowest level of exposure. Twenty-four hour survival ranged from zero to 37 percent. Control survival for five samples averaged 48 percent and ranged from zero to 91 percent. A relationship of decreasing initial and 24-hour survival with increasing exposure was apparent for both the one and two minute impingement series. Average initial survival remained above 75 percent where the fish were not subjected to air exposure. An obvious decline in survival was shown for those test conditions that included exposure to air (Table 5).

TABLE 4. RESULTS OF SEVEN SPECIES WHICH SHOWED HIGH 24-HOUR SURVIVAL TO ALL TEST CONDITIONS DESIGNED TO EVALUATE SEVERAL FISH HANDLING COMPONENTS OF A LABORATORY MODEL VERTICAL TRAVELING FINE-MESH SCREEN. VALUES DENOTE 24-HOUR UNADJUSTED SURVIVAL FOR THE 4-MINUTE IMPINGEMENT SERIES.

Test Conditions	Percentage 24-hour Unadjusted Survival						
	Paddlefish	Northern Pike	White Sucker	Channel Catfish	River Carpsucker	Smallmouth Buffalo	Quillback
Impingement only	98	97	100	100	98	99	
Impingement + spill from wet screen	96	92	100	100	94	99	99
Impingement + 1 min air exposure	-	-	99+	98	95	99+	
Impingement + 1 min air exposure + spill	-	-	99+	100	96	97	
Impingement + 3 min air exposure	92	92	100	99+	97	99+	
Impingement + 3 min air exposure + spill	95	90	100	98	96	97	88

TABLE 5. SUMMARY RESULTS OF TWO SPECIES OF LARVAL FISH WHICH SHOWED THE LOWEST SURVIVAL RESPONSE TO TEST CONDITIONS ON A LABORATORY MODEL FINE-MESH TRAVELING SCREEN. PERCENTAGE VALUES REPRESENT ARITHMETIC MEANS. DASH DENOTES NO OBSERVATION.

Impingement Duration	Average Percentage Initial and Unadjusted 24-hour (in parentheses) Survival		
	1 Min	2 Min	4 Min
Species	Striped Bass		
Test Conditions			
Impingement only	29 (2)	26 (4)	23 (2)
Impingement + spill from wet screen	10 (1)	25 (7)	6 (<1)
Impingement + 1 min air exposure	16 (0)	25 (2)	- -
Impingement + 1 min air exposure + spill	7 (0)	22 (2)	- -
Impingement + 3 min air exposure	18 (<1)	18 (2)	9 (<1)
Impingement + 3 min air exposure + spill	9 (0)	10 (1)	- -
	Striped Bass X White Bass Hybrid		
Impingement only	86 (37)	75 (5)	40 (6)
Impingement + spill from wet screen	79 (24)	83 (13)	- -
Impingement + 1 min air exposure	64 (22)	46 (0)	- -
Impingement + 1 min air exposure + spill	57 (19)	39 (0)	- -
Impingement + 3 min air exposure	37 (10)	32 (2)	- -
Impingement + 3 min air exposure + spill	33 (2)	21 (0)	- -

The four remaining species (redbreast sunfish, largemouth bass, bigmouth buffalo, and walleye) showed initial and 24-hour survival that was intermediate between the high and low values for the previously mentioned species. Redbreast sunfish and largemouth bass mean 24-hour control survival was 99 and 91 percent, respectively, compared to 59 and 56 percent for bigmouth buffalo and walleye, respectively (Table 6). Due to low numbers of bigmouth buffalo, only the two- and four-minute impingement series were tested.

A three-way ANOVA was used to evaluate the effect of the fish handling components on initial and adjusted 24-hour survival for these four species (see Appendix A). Table 7 is a summary of the ANOVA results in Appendix A. A significant effect of impingement on both initial and adjusted 24-hour survival was observed for all four species. For each species, except walleye, mean percent initial and adjusted 24-hour survival values were significantly different among impingement durations (based on Duncan's multiple range test). In each case survival was inversely related to impingement duration (Table 7). Walleye usually showed highest initial survival at four minutes impingement and highest 24-hour survival at two minutes impingement (Table 7).

Only largemouth bass were significantly affected by air exposure in both initial and 24-hour survival (Table 7). Air exposure showed a significant effect on 24-hour survival only of redbreast sunfish and walleye while air exposure showed a significant effect on initial survival only of bigmouth buffalo (Table 7). With the exception of walleye, mean survival for 3 minutes air exposure was usually lower than for either zero (impingement only) or one minute air exposure (Table 7). However, based on results of Duncan's multiple range test, these differences were not always significant.

Spilling did not have a consistent effect on survival. Lower mean survival (both initial and adjusted) was occasionally associated with spilling for a particular species and at certain impingement durations and air exposures (Table 7). However the results of the ANOVA indicated that spilling did not have a significant effect on either initial or adjusted 24-hour survival for any of the four species (Table 7).

The initial hypothesis was that a screen system which minimized air exposure by providing a reservoir of water during travel to the spill position would represent a near-optimum system. In order to evaluate this hypothesized "best" screen system, survival of impingement plus spill from a wet screen was compared with "impingement only" survival using an ANOVA nested among impingement durations (Table 8).

This test provided a comparison of survival associated with minimal handling on a vertical traveling fine-mesh screen with "impingement only" survival. Impingement would be associated with any fish screen employing the impinge-release concept. A significant main effect for initial and/or adjusted 24-hour survival was observed for three species. Walleye showed higher average 24-hour adjusted survival with "impingement plus spilling" compared to impingement only. Largemouth bass and redbreast sunfish showed lower average adjusted 24-hour survival with impingement plus spilling. The main effect for redbreast sunfish and bigmouth buffalo was most pronounced at the four minute impingement duration and at the two-minute impingement duration for largemouth bass.

TABLE 6. SUMMARY RESULTS OF FOUR SPECIES OF LARVAL FISH WHICH SHOWED MODERATE TO HIGH SURVIVAL RESPONSE TO TEST CONDITIONS ON A LABORATORY MODEL FINE-MESH TRAVELING SCREEN. DASH DENOTES NO OBSERVATION.

	Average Percentage Initial and 24-hour Survival								
	1 min			2 min			4 min		
Impingement Duration	In[1]	Un[2]	Ad[3]	In	Un	Ad	In	Un	Ad
Species	Redbreast Sunfish								
Test Conditions									
Controls (99)									
Impingement only	99+	99	98	80	77	77	46	44	42
Impingement + Spill from wet screen	91	86	86	79	73	74	15	14	14
Impingement + 1 min air exposure	98	90	89	71	68	67	20	17	17
Impingement + 1 min air exposure + spill	99	93	93	75	73	73	8	5	6
Impingement + 3 min air exposure	96	92	91	69	60	61	-	-	-
Impingement + 3 min air exposure + spill	97	88	88	51	46	46	-	-	-
	Largemouth Bass								
Controls (91)									
Impingement only	100	89	99	99+	87	99	88	46	60
Impingement + spill from wet screen	100	90	99	87	53	66	82	58	72
Impingement + 1 min air exposure	99	87	95	93	72	85	87	68	81
Impingement + 1 min air exposure + spill	96	74	87	99	85	97	83	56	69
Impingement + 3 min air exposure	96	78	91	78	64	77	72	35	48
Impingement + 3 min air exposure + spill	89	72	85	75	55	68	79	51	64

TABLE 6. (Continued)

Impingement Duration	Average Percentage Initial and 24-hour Survival								
	1 min			2 min			4 min		
	In[1]	Un[2]	Ad[3]	In	Un	Ad	In	Un	Ad
Species	Bigmouth Buffalo								
Test Conditions									
Controls (59)									
Impingement only	-	-	-	99	54	93	93	39	80
Impingement + spill from wet screen	-	-	-	92	52	91	92	28	68
Impingement + 1 min air exposure	-	-	-	100	54	91	94	42	80
Impingement + 1 min air exposure + spill	-	-	-	99+	72	100	91	33	74
Impingement + 3 min air exposure	-	-	-	100	68	98	74	36	77
Impingement + 3 min air exposure + spill	-	-	-	99+	59	98	69	17	58
	Walleye								
Controls (56)									
Impingement only	100	21	68	80	42	86	100	41	89
Impingement + spill from wet screen	99+	59	99	90	47	93	100	55	99
Impingement + 1 min air exposure	99	68	100	89	48	93	100	42	88
Impingement + 1 min air exposure + spill	99+	40	85	89	56	97	100	43	90
Impingement + 3 min air exposure	99+	20	68	89	49	93	100	40	87
Impingement + 3 min air exposure + spill	99+	15	62	91	40	87	99	36	83

[1]Initial survival.
[2]24-hour unadjusted survival.
[3]24-hour adjusted survival.

TABLE 7. SUMMARY OF ANALYSIS OF VARIANCE RESULTS OF IMPINGEMENT, AIR EXPOSURE, AND SPILLING. S DENOTES SIGNIFICANT ANOVA AT $\alpha = 0.05$. NS DENOTES NOT SIGNIFICANT.

	Species							
	Redbreast Sunfish		Largemouth Bass		Bigmouth Buffalo		Walleye	
Source	Initial	24-hr	Initial	24-hr	Initial	24-hr	Initial	24-hr
Impingement	S	S	S	S	S	S	S	S
Air Exposure	NS	S	S	S	S	NS	NS	S
Spilling	NS	NS	NS	NS	NS	NS	NS	NS
Imp. Dur. x Air Exp.	NS	NS	S	NS	S	NS	NS	S
Imp. Dur. x Spill	NS	NS	NS	NS	S	S	NS	NS
Air Exp. x Spill	NS	NS	NS	NS	S	NS	NS	NS

TABLE 8. SUMMARY OF ANALYSIS OF VARIANCE (ANOVA) RESULTS COMPARING "IMPINGEMENT PLUS SPILL FROM THE WET SCREEN" WITH "IMPINGEMENT ONLY" (THIS REFERRED TO AS "MAIN") NESTED OVER IMPINGMENT DURATIONS (LISTED AS "NESTED"). S DENOTES SIGNIFICANCE OF THE EFFECT AT $\alpha = 0.05$, NS DENOTES NOT SIGNIFICANT.

	Species							
	Redbreast Sunfish		Largemouth Bass		Bigmouth Buffalo		Walleye	
Source	Initial	24-hr	Initial	24-hr	Initial	24-hr	Initial	24-hr
Main	NS	S	S	S	NS	NS	NS	S
Nested	S	S	S	S	NS	S	NS	NS

Evaluation of Approach Water Velocity

The five species tested showed high initial and 24-hour adjusted survival under most experimental conditions (Figure 5). All five species were tested using a two-way ANOVA design including approach velocity and impingement duration as independent variables.

All five species showed a close similarity between initial and 24-hour adjusted survival values (Figure 5). This indicates that nearly all "test-induced" mortality occurred within a comparatively short period of time (usually less than 1 hour). Additional mortality which occurred during the holding period was accounted for by the holding mortality experienced by the respective control groups.

For smallmouth bass, black buffalo, and river carpsucker, approach velocity, impingement duration, and the interaction between velocity and duration all had a significant effect on both initial and 24-hour adjusted survival. For all three experiments, the interaction effect was characterized by a more pronounced decrease in survival at the longest duration and highest velocity (Figure 5).

For walleye, no significant differences in either initial or 24-hour adjusted survival was observed for either approach velocity or impingement duration. However, a slight decrease in mean survival values was seen at the highest impingement duration and slot velocity (Figure 5). For largemouth bass, only impingement duration had a significant effect ($P = 0.03$) on survival. Approach velocity and the interaction of duration and velocity had no significant effect on survival of largemouth bass.

Evaluation of Sprays

1. Adherence of larvae after passing through emergent spray.

Several tests were conducted without sprays to determine if impinged fish adhered to the screen panel during emergence. The need for a spray at the screen emergence position was apparent for most species. For both the flat vertical and curved screens nearly all fish that impinged during screen submergence remained attached to the screen fabric after the panel was raised out of the water. Species which have large larvae (e.g., channel catfish, paddlefish) would not adhere to the screen and would therefore not require an emergent spray.

Two levels of adherence were observed: (1) those that adhered to the screen without penetrating the mesh and (2) those that penetrated the mesh. In most cases the fish had not penetrated the mesh but were attached because of the adhesive properties associated with the wet fish and wet screen fabric. The emergent spray was usually very effective in rinsing those fish adhered to the screen into the tray.

In other cases, individuals were entrapped in the mesh. In this case the posterior end of the fish was observed protruding through the mesh with the head preventing the fish from passing through the screen. The emergent spray was ineffective in rinsing these entrapped larvae out of the mesh and into the tray.

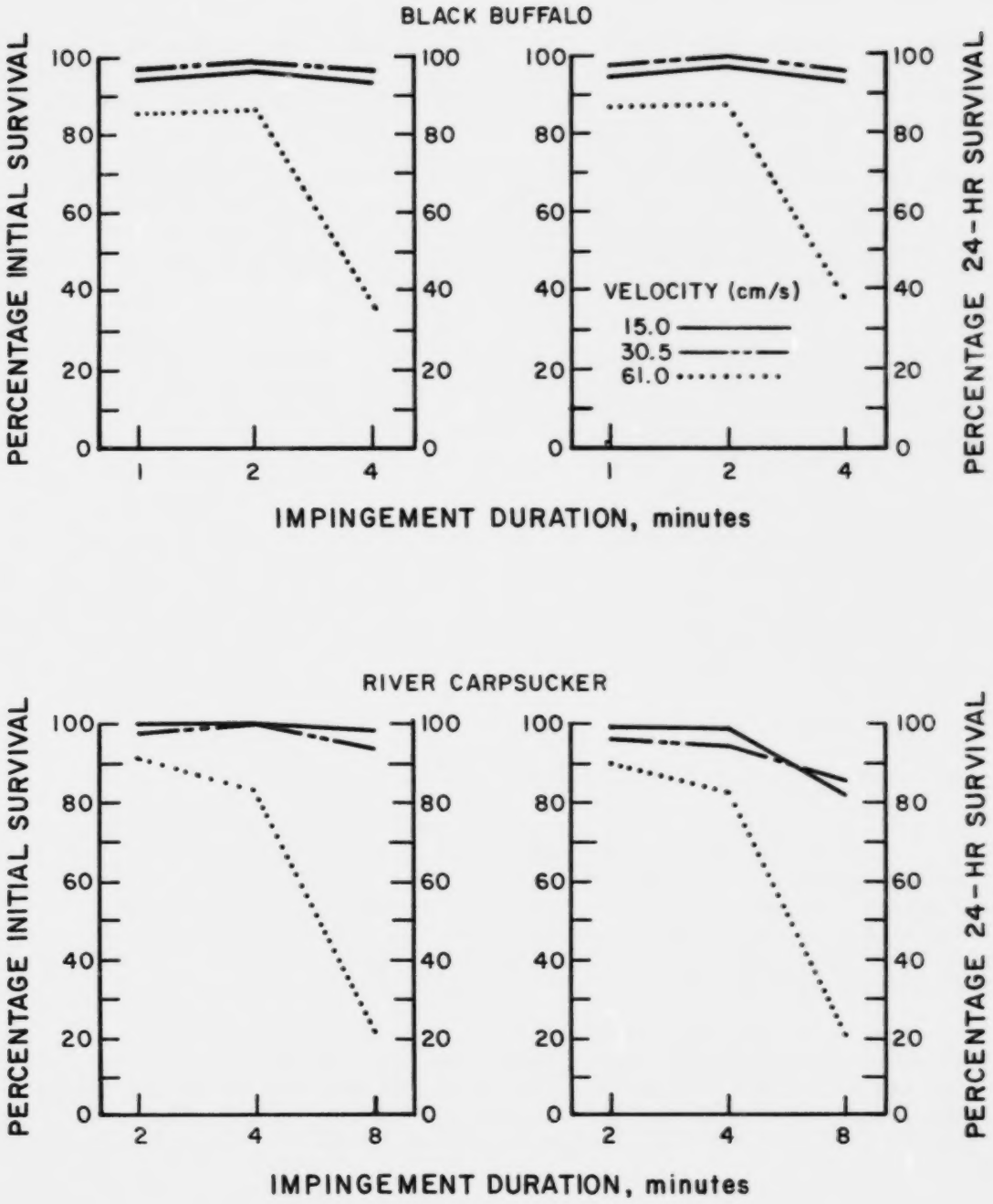
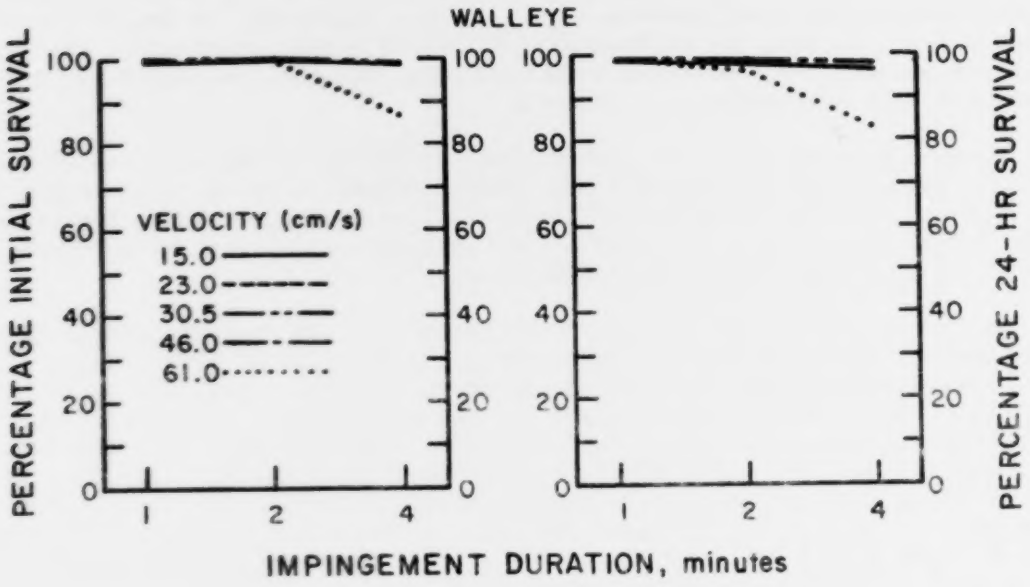


Figure 5. Effect of approach water velocity and impingement duration on survival of fish larvae subjected to impingement and spilling into return trough on a laboratory model fine-mesh screen.



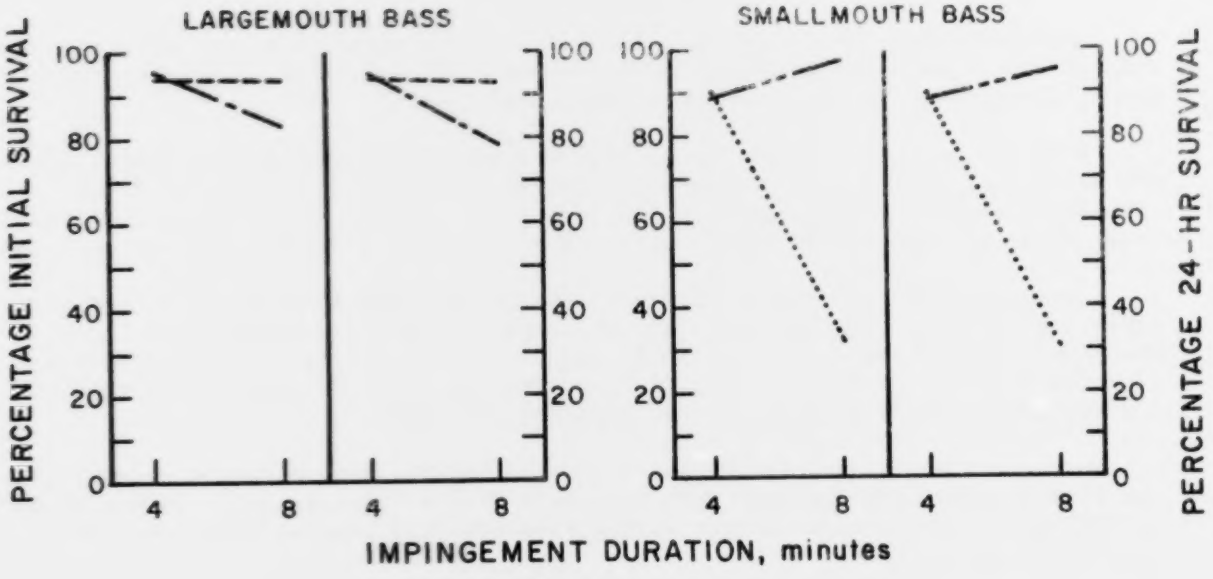


Figure 5. (Continued)

Probably the most important single factor affecting entrapment was the stoutness of the fish. Based on earlier testing, cross sectional dimension appeared to be more important than total length alone in determining whether larvae passed through the screen (Tomljanovich et al. 1977). Similarly, in the 1979 tests length alone did not account for entrapment. For example the two shortest species (striped bass and bluegill) 5.4 mm and 5.8 mm mean total lengths, respectively, did not experience any entrapment in the screen.

Longer species that experienced some entrapment in the mesh included black buffalo (mean total length = 7.1 mm), bigmouth buffalo (mean total length = 7.1 mm, and river carpsucker (mean total length = 6.6 mm). Each of these species have long threadlike bodies. The head region is typically largest with decreasing cross sectional area from the head to caudal region.

A consistent pattern was not found to explain the reason(s) for larvae being entrapped in the mesh. At the lowest approach velocity at least 25 percent of the 5-day-old black buffalo were entrapped in the mesh. However, at 30.5 cm/s and 61.0 cm/s the fish were not entraped for any of the three impingement durations. This suggests that at the lowest velocity the fish were able to move about while impinged. In so doing they may have positioned their bodies to be more susceptible to going through the screen openings (this phenomenon was observed in the tests conducted during 1976). At age 8 days none of this same group of fish, which was tested at 23.0 cm/s was entraped in the screen, but were readily rinsed into the tray.

In contrast to the results with black buffalo, 3-day-old walleye showed approximately 6 percent entrapment at the highest velocity (61 cm/s) and no entrapment at 15.0 and 30.5 cm/s. Two-day-old walleye tested at 23.0 cm/s experienced about 8 percent entrapment.

A second group of walleye (age 4 days) was tested with clogged and clean high and low lip curved, and inclined (60°) screens. In all of the tests the fish and weeds readily were washed into the screen panel tray.

A third group of walleye larvae (age unknown) similarly did not experience any entrapment in the mesh but were readily transferred to the tray with the assistance of the emergent spray. Similarly, all largemouth and smallmouth bass (ages unknown) were rinsed into the trough after passing through the emergent spray.

Seven-day-old bigmouth buffalo were tested exclusively with the curved screen comparing the effect of the high tray lip, which produced a considerable eddy in the screen panel, and a low lip which resulted in little, or no eddy formation. With the high lip no bigmouth buffalo were entrapped in the mesh. With the low lip approximately 25 percent were entrapped in the mesh.

Using the flat vertical screen, 4-day-old quillback were easily rinsed into the tray at 23.0 cm/s approach velocity and 4 minutes impingement. Most fish moved to the tray as the screen emerged so that few remained adhered when the panel approached the spray.

River carpsucker were tested extensively from age 3-6 days. Three-day-old larvae experienced a high percentage entrapment at two minutes impingement (23.0 cm/s approach velocity) and a higher entrapment rate at four minutes impingement (numbers not available).

Four-day-old river carpsucker were tested at 2, 4, and 8 minutes impingement at 61.0, 30.5, and 15.0 cm/s approach velocity, using the flat vertical screen. Also, two screen travel speeds (4.3 m/min and 6.4 m/min) were used. None of the fish tested entrapped in the screen. Average adherence after passing through the emergent spray ranged from 0 to 25.5 percent. High percentage adherence was associated with 8 minutes impingement, high screen speed, and 61.0 cm/s approach velocity. Average adherence ranged from 0 to 4.5 percent after 2 minutes impingement and from 0.6 to 6.2 percent after 4 minutes impingement. A clear relationship of approach velocity and adherence was not apparent. Adherence was often greater at 30.5 cm/s than at 15.0 or 61.0 cm/s. Comparison of high and low screen speed showed that adherence was equal to or greater for the higher screen speed at all impingement durations for both 61.0 and 15.0 cm/s approach velocity but less at 30.5 cm/s approach velocity.

Five-day-old river carpsucker were tested at 4 and 8 minutes impingement using the curved screen with high and low lip, and the flat vertical screen. All tests were conducted at 23.0 cm/s approach velocity. None of the fish impinged or adhered with the high lip screen. On the contrary, with the low lip screen after 4 and 8 minutes impingement 87 and 92 percent of the fish, respectively, adhered. Many of these fish were entrapped in the mesh. In tests with the flat screen 9 percent of the larvae adhered to the screen after passing through the emergent spray.

Six-day-old river carpsucker were used to compare the effectiveness of the sprays on a clogged screen compared to a clean screen. The flat vertical screen was approximately 30 to 40 percent covered with fragments of three species of aquatic plants found in the Holston River. After 8 minutes impingement nearly all weeds were washed into the tray and about 28 percent of the fish were entrapped in the screen mesh. With the clean screen tests, average adherence was 26 percent.

2. Adherence after passing through overhead spray.

In general, if the fish did not become entrapped in the mesh, they spilled out of the tray readily. Occasionally one to several individuals adhered to a corner of the panel or to the metal tray lip. Table 9 depicts the results of tests using the overhead spray with 11 nozzles. For those fish that became entrapped in the mesh, the overhead spray was not effective in removing them.

Several tests were conducted to evaluate spilling after the screen was covered with aquatic plants. In initial tests of curved screens with high and low lip, the weeds, water, and fish were readily emptied at the spill position.

In another series of tests using the lower volume emergent spray, much of the weed content adhered to the screen. At the spill position the overhead spray washed them into the tray but most of them did not spill into the fish return trough. With a heavy load of clogging the higher volume emergent spray would be required.

In general, there did not appear to be a significant problem with spilling. Each panel type would require a slightly different spray design to spill most effectively.

TABLE 9. AVERAGE PERCENTAGE OF FISH THAT REMAINED IN THE TRAY AFTER PASSING THROUGH THE SPILL POSITION AND SPRAY. ALL TESTS WERE CONDUCTED WITH A CLEAN SCREEN.

Species	Screen Panel Type	Average Percentage Remaining in Tray
Largemouth Bass	Flat (vertical)	0
	Curved (standard lip)	0.8
Smallmouth Bass	Flat (vertical)	0.8
	Curved (high lip)	3.4
	Curved (low lip)	1.0
Walleye	Curved (high lip)	0
	Curved (low lip)	2.4
	Flat (vertical)	0.7
	Curved (standard lip)	0.8
Bluegill	Flat (vertical)	0.3

3. Effect of emergent and overhead sprays on survival of fish larvae.

Initial testing with the mechanical sprays installed showed that only minimal spray pressures were needed to adequately rinse the larvae and weeds into and out of the trays. It was necessary to limit the force of the emergent spray to prevent forcing adhered larvae out of the screen panel. It soon became apparent from observation that sprays alone would not be an important source of mortality. Consequently, tests comparing survival using higher pressure sprays were not conducted. Sprays at the overhead position would have less effect on survival than the emergent spray since the fish are already in the tray of water and the spray does not hit directly on them.

Evaluation of Screen Panel Design

1. Adherence

Adherence of larvae during screen panel emergence has aready been discussed for flat vertical and curved screens. It was shown that an emergent spray was necessary for rinsing larvae into the panel tray. Walleye and striped bass larvae were tested to determine if the use of flat angled screens would be self-rinsing and thus obviate the need for an emergent spray.

Tests with walleye larvae and weeds showed that a partially clogged 60-degree screen required an emergent spray to rinse fish and debris into the water holding tray whereas tests conducted only with fish did not require an emergent spray. With the clean screen the larvae did not impinge but moved down the angled screen into the tray portion of the panel. Here they were agitated in an eddy for the 4-minute duration of the test. With the clogged screen the eddy was eliminated and the larvae impinged against the screen.

Comparison of adherence of five-day-old striped bass between 4.3 and 6.4 m/min screen speeds and between 60 degree and 30 degree angle screen panels revealed some clear differences. Lowest average adherence was shown for the faster screen speed for both 60 and 30 degree panels (Table 10). Paired t-tests showed a highly significant difference ($P=<0.001$) in adherence between screen speeds and a significant difference ($P=<0.01$) between screen panels. Adherence was lower on the 60 degree screen.

TABLE 10. COMPARISON OF PERCENTAGE ADHERENCE OF STRIPED BASS LARVAE BETWEEN SCREEN ANGLES AND BETWEEN SCREEN TRAVEL SPEEDS. NO SPRAY WAS USED DURING SCREEN PANEL EMERGENCE.

	Percentage Adherence			
	60 degree screen		30 degree screen	
Screen speed (m/min)	4.3	6.4	4.3	6.4
Replicates	35	81	24	72
	33	95	20	76
	31	89	30	73
$\bar{x}$	33.0	88.3	24.7	73.7

2. Spilling

Each panel shape showed a slightly different pattern of spilling. Lip angle and height as well as inside shape of the tray determined at which point during the overhead travel of the screen the tray would begin to spill and at what point it would completely empty its contents. Most screen panels would empty before spilling onto the sprocket shaft. Modification(s) may be required for some unique screen panels not tested in these experiments in order to achieve the desired spilling performance.

3. Survival

Table 11 presents the results of five screen combinations that were compared to evaluate the effect of panel shape on survival. The predominant comparison of a high lip curved screen with a low lip curved screen was designed to compare the survival of larvae that stayed in the eddy produced behind the high lip with survival of larvae that were impinged against the low lip screen panel. Of the five species tested, average 24-hour adjusted survival was significantly greater for one species on the high lip curved screen and for two species on the low lip curved screen.

The flat vertical screen was compared with each of the low lip curved, high lip curved, and standard lip curved screens. Average 24-hour adjusted survival for the flat vertical screen was greater in all six comparisons in which this panel was evaluated. These differences were significant ($P \leq 0.05$) in three comparisons. Greatest mean differences existed for those tests in which the

TABLE 11. EFFECT OF PANEL SHAPE ON SURVIVAL OF FISH LARVAE TESTED ON A LABORATORY MODEL FINE-MESH TRAVELING SCREEN. TESTS USUALLY INCLUDED IMPINGEMENT FOLLOWED BY SPILLING INTO THE FISH RETURN TROUGH. TESTS WERE CONDUCTED WITH A CLEAN SCREEN. HL C = HIGH LIP CURVED, LL C = LOW LIP CURVED, FV = FLAT VERTICAL, SL C = STANDARD LIP CURVED, FI 60 = FLAT INCLUDED 60°.

Species	Impingement Duration (min)	Average Percent Survival					
		Initial			24-hour Adjusted		
		HL C	vs	LL C	HL C	vs	LL C
River carpsucker	8	85.3		58.9	84.9		56.9*
Bigmouth buffalo	4	76.5		75.7	71.2		72.5
Striped bass	2	69.4		56.8	61.3		67.8
Smallmouth bass	8	68.8		93.3	64.2		91.9*
Walleye	4	50.9		63.7	57.3		70.4
		LL C	vs	FV	LL C	vs	FV
River carpsucker	4	85.9		95.0	83.0		89.2
Smallmouth bass	8	93.3		97.9	91.9		95.5
		SL C	vs	FV	SL C	vs	FV
Black buffalo	2	83.3		72.6	55.2		62.0
Largemouth bass	4	81.7		94.2	79.0		94.4*
Largemouth bass	8	77.4		93.2	76.4		91.7*
		HL C	vs	FV	HL C	vs	FV
Smallmouth bass	8	68.8		97.9	64.2		95.5*
		HL C	vs	FI 60	HL C	vs	FI 60
Walleye	4	50.9		18.6	57.3		42.0
		HL C	vs	FI 60	LL C	vs	FI 60
Walleye	4	63.7		18.6	70.4		42.0*

*Denotes significance at $P \leq 0.05$.

larvae did not impinge on one of the two screens being compared, e.g., the high lip curved vs flat vertical. Mean values were similar for those tests in which the larvae impinged on both screens.

Comparison of walleye survival associated with a flat inclined 60° screen compared with the low lip curved screen showed significantly lower 24-hour adjusted survival for the inclined screen. In these tests the larvae resided in an eddy in the inclined screen but impinged against the curved screen.

The results of the panel shape comparisons suggested that for most groups of fish tested, a screen panel that impinges the fish is preferred over a screen panel that allows the larvae to tumble and swim about in an eddy. Apparently the harmful effects of tumbling in a turbulent zone behind the lip is greater than the effects associated with impingement against the screen fabric.

Observations of Test-Induced Shock or Overt Signs of Stress

During the course of testing, observations on the larvae's post-test conditions were often noted to determine the length of time required for the larvae to regain normal behavior, i.e., the behavior observed prior to the test. For example, most of the species tested were swimming actively in the holding container prior to testing, but some fish showed no swimming activity for some period after the test. Often these fish lay on the bottom (either motionless or twitching) for a period of several minutes to an hour or more before resuming their normal swimming posture.

Seven-day-old bigmouth buffalo exposed to "impingement only" for four minutes on the high lip and low lip curved screens appeared quite stressed 30 minutes after the tests. Approximately 75 percent of the fish were alive at the time of the initial survival determination.

Three groups of walleye likewise showed overt signs of stress following testing. Two-day-old walleye exposed to 1, 2, and 4 minutes "impingement plus spilling" began to recover shortly after being spilled and siphoned into coolers. Initial and 24-hour survival was very high for these fish.

In tests with another group of four-day-old walleye comparing the effect of high and low lip curved screens, nearly all fish were lying on the bottom of the coolers one hour after being subjected to four minutes "impingement plus spilling." Somewhat fewer fish appeared to be stressed for these tests with the low lip (impinging screen) than with the high lip (eddy-producing screen).

A third group of walleye (age unknown) subjected to two and four minutes "impingement plus spilling" also showed some signs of stress following the test. This group recovered within two hours. A greater percentage of fish in stress was observed for those fish subjected to two minutes of being in an eddy on a curved screen than for four minutes impingement against a flat screen. These observations support the conclusion derived from survival results of screen panel comparisons that impinging the larvae is preferred over allowing them to tumble about in the screen panel.

A difference in post-test stress between 30.5 and 61.0 cm/s approach water velocity was observed for smallmouth bass larvae. After both four and eight minutes "impingement plus spilling" at 61.0 cm/s, nearly all fish were lying on

the bottom of the cooler. Within an hour these fish either recovered (began swimming) or died. After four and eight minutes "impingement plus spilling" at 15.0 cm/s velocity, there was much less evidence of test-induced stress. Most fish were swimming actively at the end of the four-minute tests. At the end of the eight-minute tests about half the number of fish were swimming.

Several other hardier species showed no or little overt stress immediately after those tests which included four minutes or less impingement time. River carpsucker showed signs of stress after eight minutes impingement but appeared to recover within a few minutes after being siphoned into the coolers.

Observations of Longer Than 24-Hour Delayed Mortality

For one group of walleye and the quillback, observations were made on longer than 24-hour survival. After the 24-hour dead count of three-day-old walleye tested at two velocities and three impingement durations, the remaining live larvae were left in the coolers for an additional 48 hours. The fish were not fed during this period and no water was added to make up for considerable leakage in the coolers. Despite the seemingly unfavorable conditions (by the end of 72 hours most of the coolers contained only a few centimeters water depth) there were very few additional dead larvae. Most appeared to be livelier than at the 24-hour mortality count.

Similarly, quillback larvae were held for 96 hours after testing without being fed and without replacing water in the coolers. Nearly all the fish were very lively at the end of 96 hours.

Evaluation of Predictive Value of Laboratory Tests

Tests were usually conducted on the earliest life stages that could be obtained for each species. It appeared that, for a given species, the ability of the fish to survive the impinge-release process would be positively correlated with its size and age. It was assumed that by testing the youngest life stages the results would represent minimum survival for the species. Few species of larval fish have survived beyond several days under laboratory conditions. This has precluded adequately evaluating the effect of size/age on survival. Often the larvae that survive up to a few weeks in the laboratory grow weaker with age. Tests with these fish can lead to erroneous conclusions about their expected survival on a prototype screen operating in the natural environment.

Results of the few species that thrived under laboratory conditions or that were obtained in their natural habitat as early juveniles suggested that when the fish which are fragile as young larvae attained early juvenile stage they were very capable of withstanding the conditions imposed by an impinge-release system. Since only very limited age ranges of larvae were usually tested for most species, it is impossible to provide an expected survival rate for a species. Each life stage of the larvae, obtained in the condition that would be expected under natural conditions, would need to be tested in order to accurately estimate survival for that species.

Test results for most species which showed high control survival and which were tested within a few days of hatching or obtained from the natural habitat probably closely approximate the percentage survival that would be expected on a prototype screen.

SECTION 4

FISH AVOIDANCE CONCEPT

MATERIALS AND METHODS

Description of Test Facility

The test facility used in this experiment simulated a range of water velocity conditions that could typically exist in a river or stream. The facility was not designed to model a prototype but rather to test the response of larvae to several combinations of approach and slot velocities, screen orientation, and amount of exposure to screen (length of screen).

The test apparatus consisted of a plexiglas flume (Figure 6) 11.9 m long by 39.4 cm wide by 39.4 cm deep. Half of the flume contained five consecutive 1.2 m long sections, each containing a flat slotted screen panel (Figure 7). Water could be withdrawn from one or more of the test sections through the slotted screen. Two directions of withdrawal were obtained by placing the screen either horizontally to form the bottom of the flume or vertically to form one wall. Smith (1977) described the design of the test flume and screening medium in detail.

Water temperature control was unavailable in the test flume. Water used in the laboratory was supplied from a 757 m^3 sump located beneath the laboratory. A few times each year the sump may be drained and refilled with chlorinated tap water. To remove the chlorine and make the water suitable for testing fish, the water was aerated by circulating it for several days through one or more test flumes or models. Since the water supply is changed infrequently, chlorine toxicity is rarely a problem. Water temperature is dependent on ambient weather conditions as well as the extent to which the several test flumes and models are operated. Flume temperatures were usually a few degrees warmer than holding water.

Acquisition and Pretest Holding of Fish Larvae

The same methods of obtaining and holding test fish described for the impinge-release tests were used for the fish avoidance experiments.

Description of Test Procedures

1. Test fish were transferred from "Living Stream" holding tanks to the Engineering Laboratory for testing via a 12 ℓ plastic container.

2. To adjust the temperature of the holding water to that of the flume water, the transfer container was immersed in flowing flume water. Water temperature was monitored periodically, and testing was not begun until

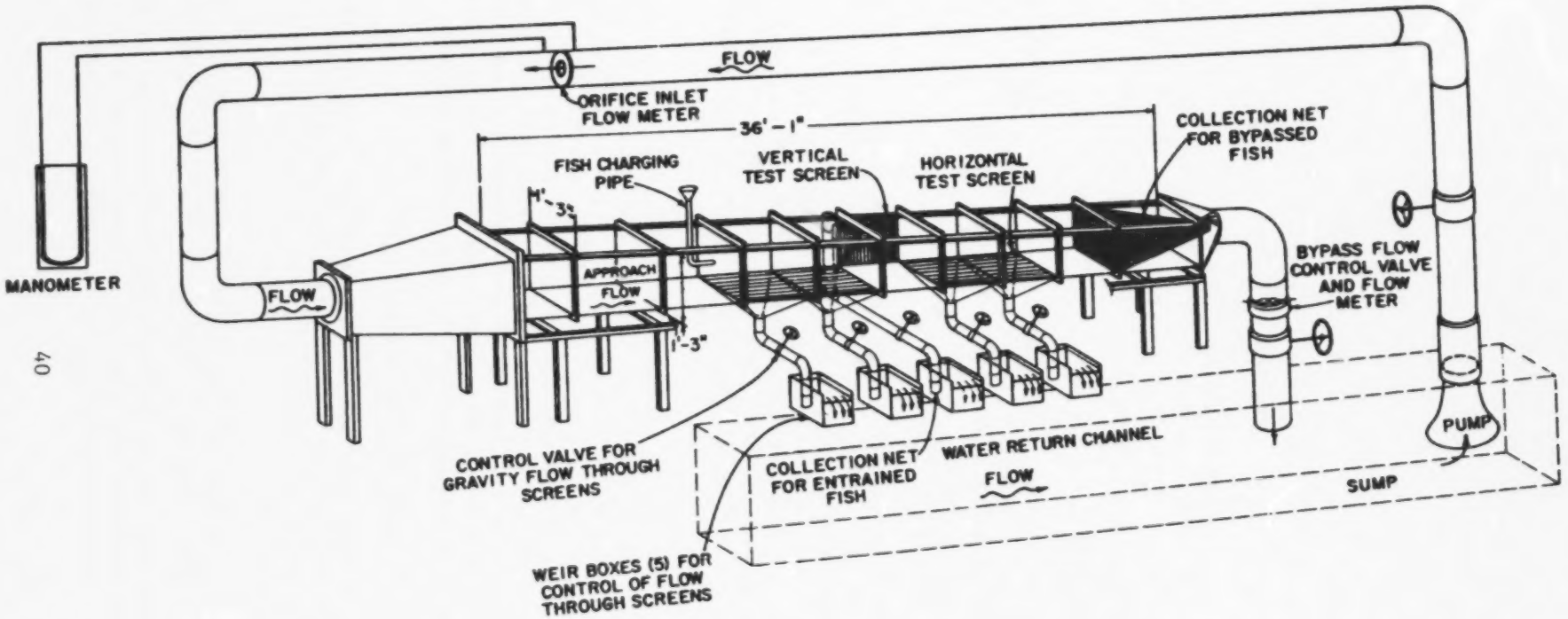


Figure 6. TVA engineering laboratory test flume for the study of fish behavior near stationary screens

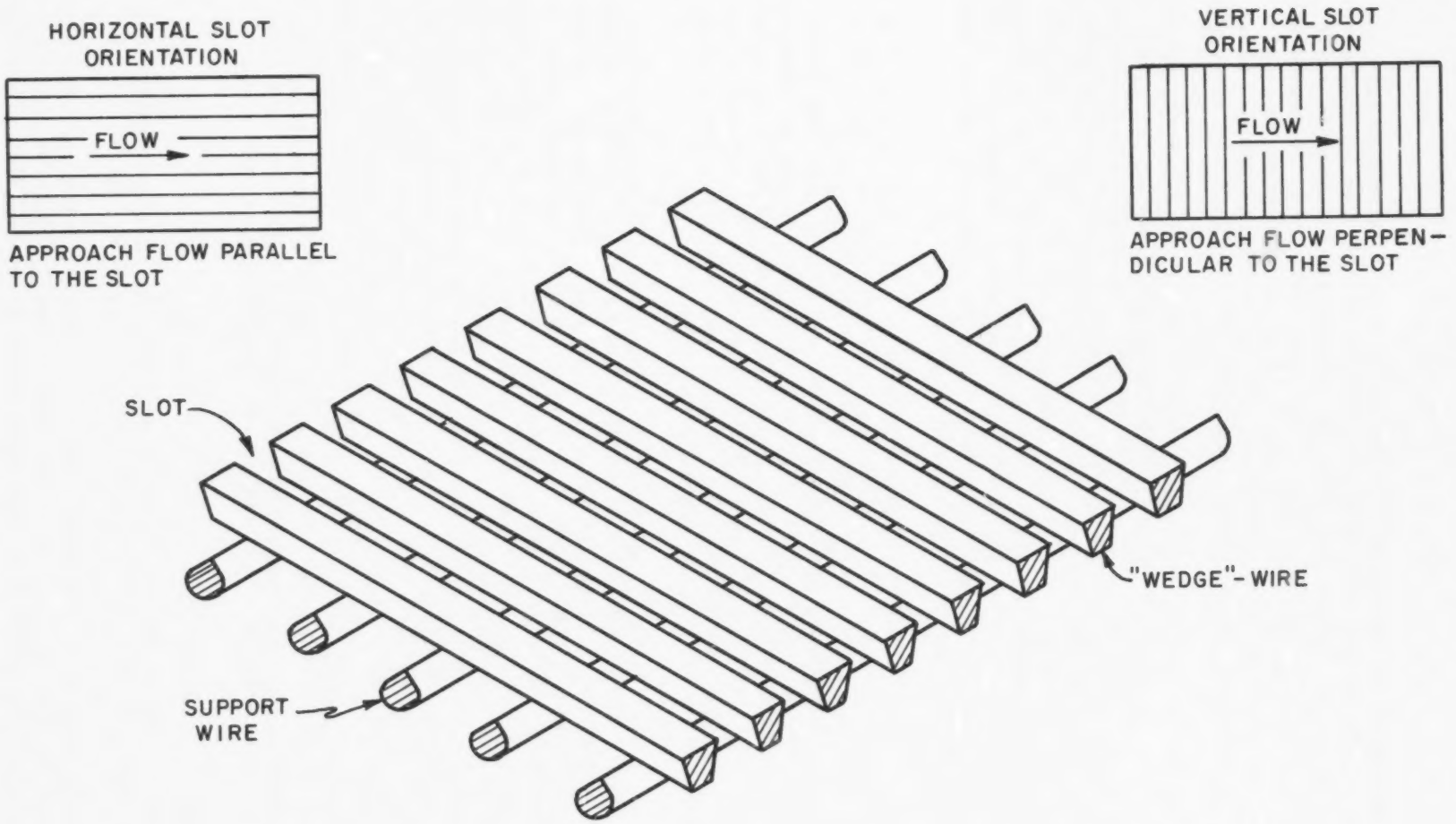


Figure 7. Stainless steel wedge wire screens used in laboratory test flume to evaluate the "fish avoidance" concept of protecting fish larvae at water intakes.

the temperature in the container was within 2 C of the flume temperature. During the temperature adjustment period, the holding water was continuously aerated, and fish were carefully observed for overt signs of thermally induced stress. The first year of study showed the fish to be livelier and more responsive when not subjected to long acclimation periods, thus the second year of testing eliminated this step. No signs of thermal shock were observed during any of the tests.

3. Experimental conditions for a particular test (screen position, screen slot width, and water velocities) were established (Table 12). This was accomplished by adjusting the valves which controlled the gravity flow of water through the screens. The flow was metered by measuring the water level in each of the five weir boxes (Figure 6). The water depth in the downstream end of the flume was held at approximately 37 cm (14.6 in) during all tests. Therefore, approach velocity (upstream of the test screens) and bypass velocity (downstream of the test screens) were a function of through-screen velocity. The open area of all screens was approximately 22 percent, regardless of slot width.

4. In each test all fish were introduced into the flume near the wall of vertical test screens. Flow on this side represented the entrainable portion, and all larvae introduced into this flow were subject to entrapment. Therefore, any fish that bypassed the screens would have shown some avoidance response. This method of introducing the fish and evaluating the avoidance response represents the major deviation between the two year's studies. In the first year fish were introduced as uniformly as possible throughout the water column and proportion of fish entrained was compared with proportion of flow entrained.

5. Depending on availability and size of each species, from several hundred to more than 1,000 individuals were poured from a 1,000 mℓ beaker into the flume via a glass tube of 2.5 cm diameter (Figure 6). As the fish drifted downstream they were either entrained, impinged, or drifted past (avoided) the screens. Entrained individuals were retrieved from a fine-mesh catch cup located in each test section weir box (Figure 6). Fish which avoided entrapment were retrieved from a collection cup fitted to the cod end of a cone-shaped collection net located downstream of the screen sections (Figure 6). Entrained fish were counted immediately. Fish which avoided entrapment were usually more numerous and were preserved and counted at a later date. Selected samples of this latter group were used to obtain average total lengths of test fish. Very few fish impinged against the screens. If a fish was too large to fit through the screen opening, it was usually able to avoid impingement. The few fish that were impinged were included with the entrained fraction. A three replicate test design was used throughout the study.

Numerical Analyses

Appendix B details the numerical analyses performed on the first year's data and gives graphic presentations of the results for each species tested.

Using these data as a base, the second year of study evaluated the effect of additional experimental variables on avoidance of entrapment. The variables tested included illumination, slot orientation, through-screen velocity, slot width, fish

TABLE 12. EXPERIMENTAL VARIABLES TESTED IN THE "FISH AVOIDANCE" CONCEPT FLUME STUDIES.

Variable		Year Tested 1	2
Screen orientation (vertical)		X	X
Screen orientation (horizontal)		X	
Slot orientation (perpendicular to flow)			X
Slot orientation (parallel to flow)		X	X
Slot width (0.5 mm)		X	X
(1.0 mm)		X	X
(2.0 mm)		X	X
Diel period (day)		X	X
Diel period (night)			X
Bottom refuge (present)			X
Bottom refuge (absent)		X	X
Screen length (number of 1.2 m test sections)			X
Velocities			
Through Screen	7.5 cm/s (.25 fps)	X	X
	15 cm/s (.50 fps)	X	X
	22.9 cm/s (.75 fps)	X	
Bypass	7.6 cm/s (.25 fps)	X	
	15 cm/s (.50 fps)	X	
	30.5 cm/s (1.0 fps)	X	
	61 cm/s (2.0 fps)	X	
Fish age (selected species)			X
Species tested			
Muskellunge (*Esox masquinongy*)		X	
Channel catfish (*Ictalurus punctatus*)		X	X
Bluegill (*Lepomis macrochirus*)		X	X
Largemouth bass (*Micropterus salmoides*)		X	X
Smallmouth bass (*Micropterus dolomieui*)		X	
Striped bass (*Morone saxatilis*)		X	
Walleye (*Stizostedion vitreum*)		X	X
Paddlefish (*Polyodon spathula*)			X
Northern pike (*Esox lucius*)			X
White sucker (*Catostomus commersoni*)			X
Striped x white bass hybrid (*Morone* sp.)			X
Sauger (*Stizostedion canadense*)			X

age, presence of a bottom refuge, and screen length (Table 12). Limited time and numbers of test fish required that emphasis be placed on certain "key" independent variables. These key variables were slot velocity, screen length, slot orientation, and diel period.

Avoidance of entrapment was the basic dependent variable in the second year's testing. Avoidance, expressed as a simple percentage value, was calculated in two ways. The effect of the experimental variables on avoidance for the entire screen was examined first, treating all five screen sections as a single screen unit. Avoidance was then calculated separately for each screen section as the percentage of available fish which avoided entrainment and impingement. The total number available at each screen section was reduced by the number of fish entrapped in the preceding (upstream) screen sections. Comparison of avoidance values by screen, from upstream to downstream, was used to estimate the effect of screen length on avoidance.

Multifactor analysis of variance (ANOVA) designs were used to examine effects of experimental independent variables on avoidance. In all cases, percentage values were transformed using an arcsin function (Sokal and Rohlf 1969). All averages presented as part of the ANOVA results were calculated with the transformed data and reconverted to the original percentage units. These averages are derived means and are not "raw" arithmetic averages. Comparisons among these values are therefore limited to the statistical analysis. Techniques available from the Statistical Analysis System (SAS), General Linear Models Procedure (Barr et al. 1976) were used to transform the data and to calculate the statistics for the multifactor ANOVA designs. Duncan's Multiple Range tests, used to compare mean avoidance among levels of each significant effect, were also calculated by SAS procedures. Although use of the Duncan's test in analyses which generally included only two levels of each main effect might appear redundant, this procedure provided information on the magnitude and relationship of significant differences indicated by the analyses of variance. Determination of significance in all statistical tests was based on an α-level of 0.05.

RESULTS AND DISCUSSION

The ability of seven species of fish in the larval to early juvenile stages to avoid entrainment through stationary slotted screens was tested the first year of the fish avoidance study. The mean total lengths of these fishes ranged from 5.6 mm to 21.5 mm. These species exhibited a wide range in behavior, which affected their overall performance in the test flume. Within-replicate variability was usually high for most species and was probably due to behavioral characteristics which resulted in nonhomogeneous distributions of the fish in the water column.

The results of the 296 separate test conditions (excluding the first experiment with muskellunge) showed that for all three slot widths, the fishes tested could avoid entrapment to some extent (Appendix B).

The initial hypothesis that larval fish are incapable of detecting and responding to entraining flows was rejected. All of the larval fish species tested, except very young muskellunge, showed some ability to avoid entraining currents under most experimental conditions. Many species showed considerable avoidance, often resulting in nearly all of the fish in a given test avoiding entrapment (Appendix B).

During the second year of study, 243 tests were conducted. Larvae of the nine species tested ranged in age from 3 to 18 days (Table 13), with average total lengths ranging from 5.7 mm (5-day-old striped bass hybrid) to 14.7 mm (4-day-old paddlefish). Size of larvae was more dependent on species than age. Paddlefish, northern pike, white sucker, and channel catfish were longer than the older striped-white bass hybrid and sauger tested.

Table 14 shows the combinations of variables that were tested and percent avoidance for all screen sections treated as a single unit. Since the objective of the study was to evaluate the effect of several variables rather than to simply determine conditions that would result in high avoidance for "problem species," those conditions which would yield either low or high entrapment were not tested. A large range in average avoidance among combinations of variables was observed for all species.

Avoidance Response to Total Length of Screen

Nine different experimental designs were applied to the data, eight of which included slot velocity as an independent variable (Table 15). ANOVA techniques indicated that all independent variables had a significant effect on avoidance for nearly every species. Interaction between these variables also affected avoidance in many cases.

1. Independent Variable = Slot Velocity

Northern pike was the only species tested with this design. Slot velocity had a highly significant effect on avoidance. Duncan's multiple range test indicated that mean avoidance at slot velocity 7.5 cm/s (80.5 percent) was significantly greater than at 15.0 cm/s (14.9 percent). The observed low avoidance of this species at the high slot velocity is consistent with adaptations to the natural habitat during young life stages. Flooded meadows and marshes, characterized by very still or slowly moving water, are utilized as nursery habitat by northern pike (Eddy and Underhill, 1974).

2. Independent Variables = Slot Velocity x Slot Orientation

This design was tested for five species (Table 15). Slot velocity and slot orientation both had a significant effect on avoidance. Duncan's multiple range tests indicated that the lower slot velocity resulted in significantly higher avoidance (Table 16). The effect of slot orientation, however, was species dependent. Greater avoidance occurred with the vertical slot orientation for white sucker, channel catfish, and sauger, whereas striped-white bass hybrid and largemouth bass showed significantly greater avoidance with the horizontal orientation.

The slot velocity x slot orientation interaction effect was significant for white sucker and channel catfish (Table 17). In each case, the effect of slot orientation was greater at the lower slot velocity. At the higher velocity fish apparently have little chance of escaping once contact is made, regardless of slot orientation. At the lower slot velocity the probability of escaping is apparently greater with the vertical slot orientation. This was expected since in this case the slot is oriented perpendicular to the length of the fish.

TABLE 13. AGE AND MEAN SIZE OF FISH TESTED IN THE "FISH AVOIDANCE" LABORATORY FLUME. TOTAL LENGTHS OF 100 INDIVIDUALS WERE MEASURED FROM SELECTED SAMPLES FOR EACH DAY OF TESTING.

Species	Age (days)	Mean Total Length (mm)	Range
Paddlefish	4	14.7	13.0-16.0
	5	15.0	13.5-16.5
Northern pike	6	14.2	13.0-15.5
White sucker	3	13.8	13.0-14.5
	4	13.5	12.0-14.5
	5	14.0	13.0-16.0
	9	14.3	13.0-15.5
	10	14.0	13.0-15.0
Channel catfish	3	11.4	10.0-12.5
	4	12.2	10.5-14.0
	5	12.9	11.0-14.5
	6	13.4	12.0-14.5
striped x white bass	5	5.7	5.0-6.0
	6	5.6	5.0-6.0
	13	6.3	4.5-7.0
	14	6.5	5.0-7.5
	16	7.3	6.0-8.0
Bluegill	12	10.3	9.0-13.0
	13	10.7	9.0-16.0
Largemouth bass	17	13.0	12.0-16.0
	18	14.2	12.0-22.5
Sauger	5	7.5	7.0-8.0
	9	8.4	7.5-9.5
Walleye	4	8.8	7.0-9.5
	5	9.0	8.0-10.0

TABLE 14. SUMMARY OF ALL "FISH AVOIDANCE" TESTS THAT WERE CONDUCTED IN THE 2ND TEST YEAR. VALUES DENOTE THE MEAN PERCENTAGE (ARITHMETRIC AVERAGE) OF FISH THAT AVOIDED THE ENTIRE 6.1 m LENGTH OF TEST SCREEN. EACH VALUE USUALLY REPRESENTS A MEAN OF THREE REPLICATES. IN A FEW CASES DIFFERENT AGES WERE COMPARED, AND THE MEAN IS BASED ON SIX OR NINE TESTS.

Slot Width (mm)	Slot Orientation	Diel Period	Bottom Refuge	Slot Vel. (cm/s)	Percentage Avoidance Larval Fish Species[1]								
					W	SBH	CC	WS	S	BG	P	LMB	NP
0.5	Perpendicular	Day	No	7.5	100	97[2]	-	-	-	-	-	-	-
0.5	Perpendicular	Night	No	7.5	-	91[2]	-	-	-	-	-	-	-
0.5	Perpendicular	Day	No	15.0	96	42[2]	-	-	-	-	-	-	-
0.5	Perpendicular	Night	No	15.0	-	25[2]	-	-	-	-	-	-	-
1.0	Perpendicular	Day	No	7.5	97	85	100	99+	97	99+	-	-	-
1.0	Parallel	Day	No	7.5	88	89	-	-	97	-	-	-	-
1.0	Perpendicular	Night	No	7.5	87	28	-	91	76	-	-	-	-
1.0	Parallel	Night	No	7.5	42	-	-	-	-	-	-	-	-
1.0	Perpendicular	Day	No	15.0	47	32	99+	86	67	99+	-	-	-
1.0	Parallel	Day	No	15.0	61	35	-	-	86	-	-	-	-
1.0	Perpendicular	Night	No	15.0	14	-	-	71	6	-	-	-	-
1.0	Parallel	Night	No	15.0	3	-	-	-	-	-	-	-	-
2.0	Perpendicular	Day	No	7.5	-	-	98	92	-	94	93	94	81
2.0	Parallel	Day	No	7.5	-	-	44	76	-	-	84	96	-
2.0	Perpendicular	Night	No	7.5	-	-	-	96	-	81	86	-	-
2.0	Parallel	Night	No	7.5	-	-	60	-	-	-	59	-	-
2.0	Perpendicular	Day	Yes	7.5	-	-	-	86	-	-	-	-	-
2.0	Parallel	Day	Yes	7.5	-	-	90	-	-	-	-	-	-
2.0	Perpendicular	Day	No	15.0	-	-	32	49	-	82	75	69	15
2.0	Parallel	Day	No	15.0	-	-	11	52	-	-	60	75	-
2.0	Perpendicular	Night	No	15.0	-	-	-	38	-	46	51	-	-
2.0	Parallel	Night	No	15.0	-	-	12	-	-	-	28	-	-
2.0	Perpendicular	Day	Yes	15.0	-	-	-	71	-	-	-	-	-
2.0	Parallel	Day	Yes	15.0	-	-	57	-	-	-	-	-	-

1. W = Walleye, SBH = striped x white bass, CC = Channel catfish, WS = White sucker, S = Sauger BG = Bluegill, P = Paddlefish, LMB = Largemouth bass, NP = Northern pike.

2. Only four sections of screen were available for these tests.

TABLE 15. A SUMMARY OF THE EXPERIMENTAL DESIGNS USED TO INVESTIGATE "FISH AVOIDANCE" DURING THE SECOND TEST YEAR. THE FOLLOWING ABBREVIATIONS WERE USED TO REPRESENT THE EXPERIMENTAL VARIABLES: SW = SLOT WIDTH, SO = SLOT ORIENTATION, DP = DIEL PERIOD, BR = BOTTOM REFUGE, SV = SLOT VELOCITY, AND FA = FISH AGE. AN "X" IN A VARIABLE COLUMN INDICATES THAT THIS VARIABLE WAS TREATED AS AN INDEPENDENT VARIABLE IN ONE OF THE NINE EXPERIMENTAL DESIGNS USED.

Experiment No.	Potential Test Variables						Species Tested
	SW	SO	DP	BR	SV	FA	
1	2.0 mm	vert	day	no	X	-	northern pike
2	2.0 mm	X	day	no	X	-	white sucker, channel catfish, largemouth bass
	1.0 mm	X	day	no	X	-	striped x white bass sauger
3	2.0 mm	X	X	no	X	-	paddlefish
	1.0 mm	X	X	no	X	-	walleye
4	2.0 mm	horiz	X	no	X	-	channel catfish
	2.0 mm	vert	X	no	X	-	bluegill
	1.0 mm	vert	X	no	X	-	sauger
	0.5 mm	vert	X	no	X	-	striped x white bass
5	1.0 mm	vert	X	no	7.5 cm/s	-	striped x white bass
6	X	vert	X	no	X	-	white sucker
7	X[1]	vert	day	no	X	-	channel catfish, bluegill
	X[1]	vert	day	no	X	-	walleye
8	2.0 mm	horiz	day	X	X	-	channel catfish
	2.0 mm	vert	day	X	X	-	white sucker
9	2.0 mm	horiz	day	no	X	X	white sucker
	1.0 mm	vert	day	no	X	X	striped x white bass, sauger

[1]Channel catfish and bluegill were tested with the 1.0 and 2.0 mm slot widths while walleye were tested with the 0.5 and 1.0 mm slot widths.

TABLE 16. RESULTS OF DUNCAN'S MULTIPLE RANGE TESTS FOR SIGNIFICANT MAIN EFFECTS OF ANOVA ANALYSES FOR SLOT VELOCITY AND SLOT ORIENTATION.

Species	Mean Avoidance (%)			
	Slot Velocity (cm/s)		Slot Orientation	
	7.5	15.0	Vertical	Horizontal
White sucker	82.3	51.4	74.3	65.3
Channel catfish	68.4	18.1	74.5	27.8
Striped x white bass	87.9	31.9	59.5	68.9
Largemouth bass	95.5	72.4	84.2	88.0
Sauger	98.2	89.9	96.7	92.6

TABLE 17. MEAN AVOIDANCE FOR THE COMBINED LEVELS OF SLOT VELOCITY AND SLOT ORIENTATION FOR TWO SPECIES WHICH SHOWED SIGNIFICANT INTERACTION IN A TWO-WAY ANOVA DESIGN (SLOT VELOCITY AND SLOT ORIENTATION).

Slot Velocity (cm/s)	Slot Orientation	Mean Avoidance (%)	
		White Sucker	Channel Catfish
15.0	Vertical	48.8	32.3
15.0	Horizontal	52.7	10.9
7.5	Vertical	91.9	97.6
7.5	Horizontal	76.3	43.9

3. Independent Variables = Slot Velocity x Slot Orientation x Diel Period

This design was tested with paddlefish and walleye (Table 15). All three independent variables showed significant main effects for avoidance by both species. Duncan's multiple range test indicated significantly higher mean avoidance values for low slot velocity, vertical slot orientation, and daylight period (Table 18).

TABLE 18. RESULTS OF DUNCAN'S MULTIPLE RANGE TESTS FOR SIGNIFICANT MAIN EFFECTS OF ANOVA ANALYSES FOR SLOT VELOCITY, SLOT ORIENTATION, AND DIEL PERIOD.

	Mean Avoidance (%)					
	Slot Velocity (cm/s)		Slot Orientation		Diel Period	
Species	7.5	15.0	Vertical	Horizontal	Day	Night
Paddlefish	82.0	54.6	78.5	59.4	79.5	58.1
Walleye	83.2	29.1	68.7	49.8	76.0	40.4

Interaction effect for slot velocity x slot orientation was significant only for walleye and was similar to that described previously; i.e., the effect of slot orientation was greater at the lower slot velocity (Table 19).

Diel period x slot orientation interaction effect was significant for both paddlefish and walleye. The effect of slot orientation was apparently greater during night tests. Both species were more vulnerable to entrapment by the parallel slot screen at night. The remaining two-way interaction term, slot velocity x diel period, was not significant in either analysis.

TABLE 19. MEAN AVOIDANCE FOR COMBINED LEVELS OF SLOT VELOCITY AND SLOT ORIENTATION (WALLEYE) AND DIEL PERIOD AND SLOT ORIENTATION (PADDLEFISH AND WALLEYE) FOR SPECIES WHICH SHOWED SIGNIFICANT INTERACTIONS IN A THREE-WAY ANOVA DESIGN (SLOT VELOCITY, SLOT ORIENTATION, AND DIEL PERIOD).

		Mean Avoidance (%)	
Slot Velocity (cm/s)	Slot Orientation		Walleye
15.0	Vertical		30.8
15.0	Horizontal		27.4
7.5	Vertical		93.3
7.5	Horizontal		69.2
Diel Period		Paddlefish	Walleye
Day	Vertical	85.3	79.4
Day	Horizontal	72.9	72.3
Night	Vertical	70.6	56.2
Night	Horizontal	44.0	23.1

4. Independent Variables = Slot Velocity x Diel Period

These were the predominant experiments used to examine the effect of diel period (Table 15). With the sole exception of diel period for channel catfish, both independent variables had a significant effect on avoidance. Duncan's multiple range tests showed the usual response to slot velocity (i.e., lower slot velocity resulted in significantly higher mean avoidance (Table 20).

TABLE 20. RESULTS OF DUNCAN'S MULTIPLE RANGE TESTS FOR SIGNIFICANT MAIN EFFECTS OF ANOVA ANALYSES FOR SLOT VELOCITY AND DIEL PERIOD.

	Mean Avoidance (%)			
	Slot Velocity (cm/s)		Diel Period	
Species	7.5	15.0	Daylight	Night
Channel catfish	49.4	11.1	27.8[1]	37.1[1]
striped x white bass	94.5	33.9	77.2	64.4
Bluegill	88.5	65.7	88.9	65.0
Sauger	87.1	24.6	74.8	44.6

[1]Not significantly different.

All species except channel catfish showed significantly higher mean avoidance during daylight tests (Table 20). The response of channel catfish is consistent with the described habits of this species. Channel catfish are primarily nocturnal. Pflieger (1975) noted that during early life stages, young channel catfish seek secluded areas characterized by semidarkness. Specific behavioral adaptations associated with nocturnal activity probably account for the higher (although not significant) avoidance during night testing.

These results indicated that orientation to visual stimuli is important in the overall avoidance response. The interaction effect of slot velocity and diel period was not significant for any species.

5. Independent Variables = Diel Period

This experiment was conducted with striped x white bass (Table 15). As in the case of the previous design, diel period was shown to have a significant effect on avoidance. Duncan's multiple range test indicated that mean avoidance during daylight (77.8 percent) was significantly greater than during night (28.0 percent).

6. Independent Variables = Slot Velocity x Diel Period x Slot Width

This design was tested only with white sucker (Table 15). All three independent variables had a significant effect on avoidance. Low slot velocity, daylight period, and small slot width again resulted in higher avoidance (Table 21).

TABLE 21. RESULTS OF DUNCAN'S MULTIPLE RANGE TESTS EXAMINING SIGNIFICANT MAIN EFFECTS OF ANOVA ANALYSES FOR SLOT VELOCITY, DIEL PERIOD, AND SLOT WIDTH AS INDEPENDENT VARIABLES.

	Mean Avoidance (%)					
	Slot Velocity (cm/s)		Diel Period		Slot Width (mm)	
Species	7.5	15.0	Day	Night	1.0	2.0
White sucker	95.3	63.4	86.4	78.7	89.7	74.2

Slot velocity x diel period interaction was not significant in this experiment. The remaining two interaction terms (slot width x diel period and slot width x slot velocity) each showed a significant effect on avoidance (Table 22). The effect of diel period was greater for 1.0 mm than for 2.0 mm slot width screens and a greater effect of slot velocity was shown for the larger slot size. Therefore, for white sucker, avoidance appeared to be related to visual stimuli and was strongest for the 1.0 mm screen.

TABLE 22. MEAN AVOIDANCE FOR THE COMBINED LEVELS OF SLOT WIDTH AND DIEL PERIOD AND SLOT WIDTH AND SLOT VELOCITY: FOR WHITE SUCKER, WHICH SHOWED SIGNIFICANT INTERACTION EFFECTS IN A THREE-WAY ANOVA DESIGN (SLOT VELOCITY X DIEL PERIOD X SLOT WIDTH).

Slot Width (mm)	Diel Period	Mean Avoidance (%) White Sucker
1.0	Day	94.9
1.0	Night	82.9
2.0	Day	74.3
2.0	Night	74.1
Slot Width (mm)	**Slot Velocity (cm/s)**	**White Sucker**
1.0	15.0	79.7
1.0	7.5	96.5
2.0	15.0	43.7
2.0	7.5	93.9

7. Independent Variables = Slot Velocity x Slot Width

This design was tested with three species (Table 15). Both slot velocity and slot width had a significant effect on avoidance in each analysis. Duncan's multiple range tests showed significantly higher avoidance associated with the lower slot velocity and narrow slot widths (Table 23).

TABLE 23. RESULTS OF DUNCAN"S MULTIPLE RANGE TESTS FOR SIGNIFICANT MAIN EFFECTS OF ANOVA ANALYSES FOR SLOT VELOCITY AND SLOT WIDTH.

	Mean Avoidance (%)				
	Slot Velocity (cm/s)		Slot Width (mm)		
Species	7.5	15.0	0.5	1.0	2.0
Channel catfish	99.4	79.5		99.9	74.5
Bluegill	98.3	95.0		99.9	88.9
Walleye	99.4	77.4	99.9	79.4	

The slot width x slot velocity interaction effect was significant in every analysis (Table 24). As in the preceding analysis, the effect of velocity was more pronounced with the larger slot width. The larvae in these tests were too large to pass through the smaller slots and were able to avoid impinging on the screens.

TABLE 24. MEAN AVOIDANCE FOR THE COMBINED LEVELS OF SLOT WIDTH AND SLOT VELOCITY FOR THREE SPECIES WHICH SHOWED SIGNIFICANT INTERACTION IN A TWO- WAY ANOVA DESIGN (SLOT VELOCITY X SLOT WIDTH).

		Mean Avoidance (%)		
Slot Width (mm)	Slot Velocity (cm/s)	Channel catfish	Bluegill	Walleye
0.5	15.0	-	-	95.8
0.5	7.5	-	-	100.0
1.0	15.0	99.8	98.9+	46.7
1.0	7.5	100.0	99.9+	97.5
2.0	15.0	32.3	81.9	-
2.0	7.5	97.6	94.3	-

8. Independent Variables = Slot Velocity x Bottom Refuge

This design examined the effect of a bottom refuge on avoidance for white sucker and channel catfish (Table 15). Slot velocity and bottom refuge had a

significant effect on avoidance for both species; significantly higher avoidance occurred for low slot velocity and a bottom refuge (Table 25).

TABLE 25. RESULTS OF DUNCAN'S MULTIPLE RANGE TESTS FOR SIGNIFICANT MAIN EFFECTS OF ANOVA ANALYSES FOR SLOT VELOCITY AND BOTTOM REFUGE.

	Mean Avoidance (%)			
	Slot Velocity (cm/s)		Bottom Refuge	
Species	7.5	15.0	Present	Absent
White sucker	79.8	59.3	79.3	65.3
Channel catfish	71.0	40.5	73.3	27.8

Increased avoidance with the bottom refuge was especially apparent for channel catfish. These results are consistent with the tendency of this species to remain very close to the bottom of the flume. The slot velocity x bottom refuge interaction term was not significant for either species.

9. Independent Variables = Slot Velocity x Fish Age

This design was an attempt to determine the extent that swimming ability (assumed to be directly related to fish age in this experiment) contributed to fish avoidance of the wedge-wire screen. Three species were tested (Table 15). Slot velocity and fish age significantly affected avoidance in each analysis. Duncan's multiple range tests indicated significantly higher mean avoidance for low slot velocity and older fish (Table 26).

TABLE 26. RESULTS OF DUNCAN'S MULTIPLE RANGE TESTS FOR SIGNIFICANT MAIN EFFECTS OF ANOVA ANALYSES FOR SLOT VELOCITY AND FISH AGE.

	Mean Avoidance (%)	
	Slot Velocity (cm/s)	
Species	7.5	15.0
White sucker	76.3	52.7
Striped x white bass	86.2	32.0
Sauger	97.4	72.8

	Fish Age					
	5 days	6 days	9 days	10 days	13 days	15 days
White sucker	60.1			70.2		
striped x white bass		54.9			59.5	
Sauger	74.8		96.7			

For two of the three species, the interaction effect of slot velocity and fish age was significant (Table 27). In both cases, the entrapment effect of velocity was greater for young fish. However, since growth is also a factor, this interaction may partially reflect the slot width x slot velocity effect described previously. The results suggested that a prototype would probably entrap a relatively narrow age (size) range of fish.

TABLE 27. MEAN AVOIDANCE FOR THE COMBINED LEVELS OF FISH AGE AND SLOT VELOCITY FOR TWO SPECIES WHICH SHOWED SIGNIFICANT INTERACTION IN A TWO-WAY ANOVA DESIGN (SLOT VELOCITY AND FISH AGE).

Fish Age (days)	Slot Velocity (cm/s)	Mean Avoidance (%)	
		White Sucker	Walleye
5	15.0	39.3	42.0
5	7.5	77.4	95.1
9	15.0	-	93.1
9	7.5	-	99.0
10	15.0	64.8	-
10	7.5	75.2	-

Avoidance Response to Each Individual Screen Section

Nearly all of the experimental designs just discussed were also tested using avoidance of individual screen sections as the dependent variable. This analysis provided an additional independent variable, screen section position. In each experimental design, avoidance of each 2.1 m long screen section showed nearly identical patterns of response to the independent variables as previously described for the dependent variable of combined screen sections.

In every analysis, screen section position in the flume had a significant effect on avoidance. Duncan's multiple range tests showed that highest avoidance always occurred for one of the first (upstream) three screens. In most analyses, the subset of mean avoidance from one or more of these first three sections (numbers 1 to 3) was significantly higher than mean avoidance on the other screen sections.

Decreased avoidance of the downstream screens is probably due to decreased current velocity at the end of the flume. Figure 8 illustrates the effect of water withdrawal through the test screens on velocity in the flume for the two slot velocities. The higher slot velocity resulted in lower velocity at the downstream end of the flume. The velocity at the upstream end of the flume was sufficiently high at both slot velocities to preclude any of the larvae from maintaining a position in the current. However, some species were able to swim for appreciable lengths of time in the last screen section, thus increasing the period of susceptibility to entrapment. This was especially true for the higher slot velocity tests, in which the velocity in the flume was minimal and in some cases negative.

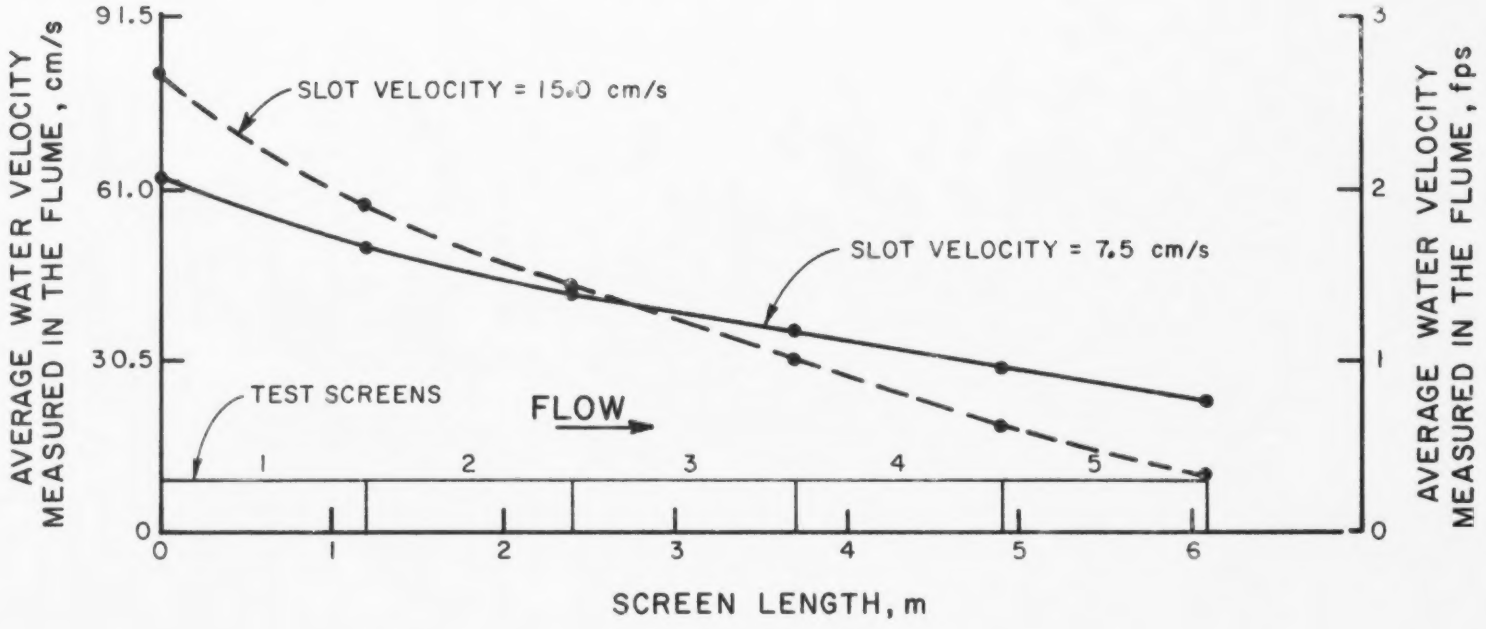


Figure 8. Average water velocity in the "fish avoidance" flume (based on nine cross-sectional measurements at six locations) from upstream end of test section #1 to downstream end of test section #5 for two slot velocities.

Net avoidance from upstream to downstream was used to examine avoidance response with respect to screen length (Figure 9). Each slot velocity was plotted separately since this was the major independent variable and because of the strong effect of slot velocity x screen section interaction on avoidance. Each species showed a large difference in avoidance between slot velocities. At the higher slot velocity three species showed a nearly linear decline in avoidance from upstream to downstream. On the other hand, white sucker, largemouth bass, and walleye were distinctly affected by slot velocity at the downstream-most section. Avoidance decreased markedly between the fourth and fifth sections at the higher slot velocity for these species, probably due largely to reduced velocity in the flume which enabled the fish to remain in the downstream test section for extended periods of time.

To better understand the importance of swimming on the avoidance response, several tests were repeated using the same individuals after they were dead and preserved in formalin. White sucker, which have relatively large, filiform larvae, and walleye, which have smaller, stouter larvae, were tested in daylight with the vertical slot orientation and no bottom refuge. White sucker were tested with the 2.0 mm slot, and walleye were tested with the 1.0 mm slot. The live larvae clearly showed significantly greater avoidance (based on a paired t-test) for both slot velocities (Table 28).

TABLE 28. COMPARISON OF MEAN AVOIDANCE BETWEEN DEAD AND LIVE LARVAE OF TWO SPECIES AT EACH SLOT VELOCTIY.

Slot Velocity (cm/s)	White sucker		Walleye	
	Dead	Live	Dead	Live
7.5	69	92	12	97
15.0	4	49	18	47

Dead larvae showed high impingement, as opposed to live fish. The walleye results were questionable owing to greater dead fish "avoidance" with 15.0 cm/s slot velocity compared to 7.5 cm/s slot velocity. The results of tests with dead fish indicated that a portion of each avoidance value for live fish tests was due to one or more factors not related to swimming ability. The large difference in dead white sucker "avoidance" between slot velocities suggested that turbulence, velocity in the flume, and/or percent of total flow entrained through the test screens affected the portion of avoidance not related to swimming of live larvae.

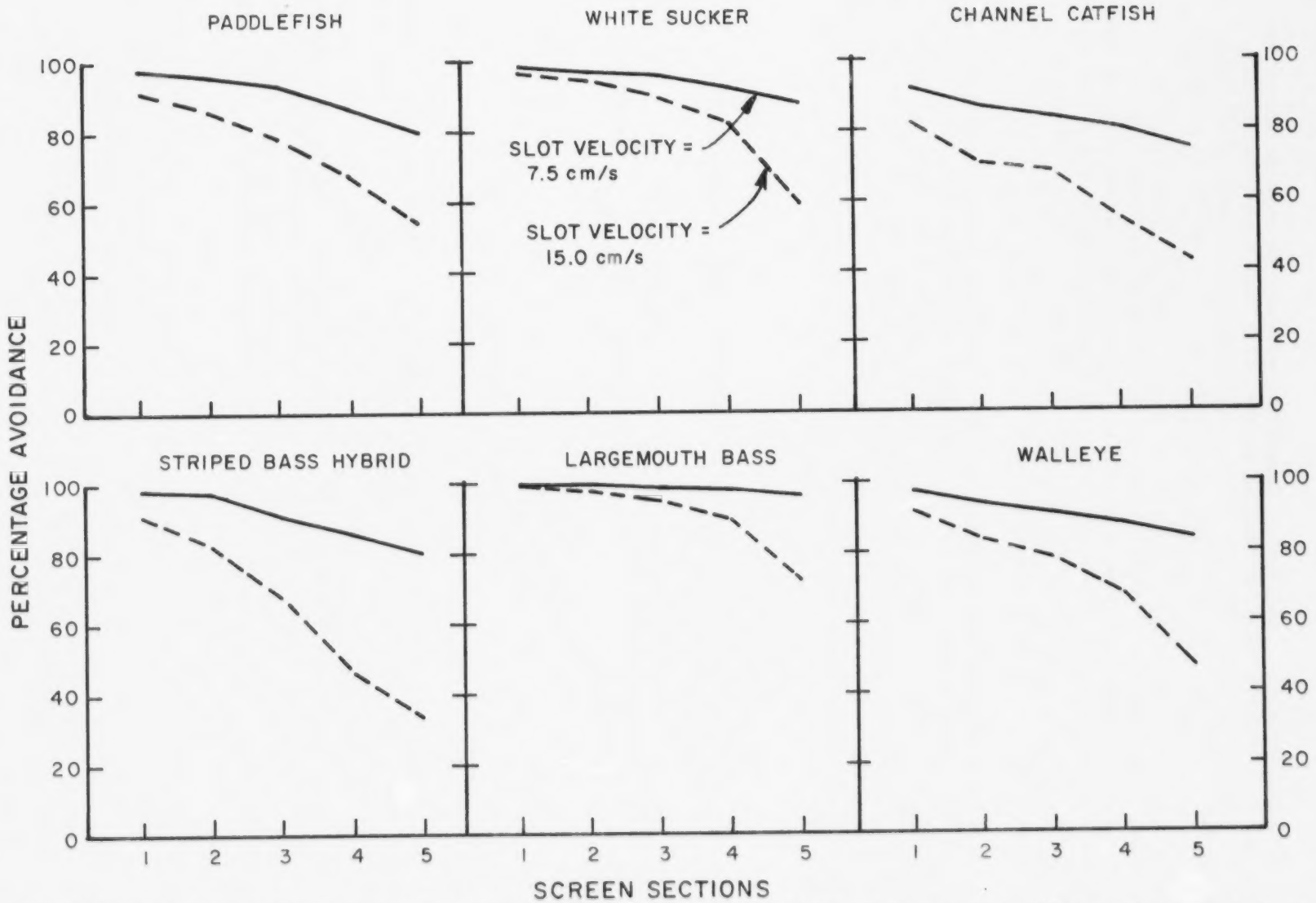


Figure 9. Effect of screen length (number of adjacent 1.2-m-long screens) on entrapment avoidance by larval fish. Each line represents cumulative entrapment (expressed as percentage net avoidance) from upstream (screen 1) to downstream (screen 5). All values are averages over several test conditions (slot width, slot orientation, diel period, fish age, and presence or absence of a bottom refuge).

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GLOSSARY

Approach Velocity--The calculated or measured velocity of water in the flume upstream of the test screen through which water is withdrawn.

Avoidance (Avoided)--Refers to a significant difference between observed and expected proportion of fish which bypass the test screen in which observed is greater than expected.

Bypass Velocity--The velocity of the remaining portion of the total flow of water in the test flume after a portion has been withdrawn through the test screen. Bypass velocity is calculated or measured at a point immediately downstream of the test section being used in a particular experiment.

Entrainment--The transport of fish through a test screen by water current.

Entrapment--The arithmetic sum of number of fish entrained and number impinged.

Immediate Survival--The proportion of the retained fish which were alive approximately one hour after a test.

Impingement--The process of a fish being forced against a test screen by water current and unable to escape throughout the duration of a test.

Larval Fish--Developmental stage of fish defined as extending from the period of hatching to full development of fin rays. Used throughout this report to refer to fish a few days to a few weeks of age. This period of development is divided into the prolarval stage (from time of hatching until absorption of yolk sac is complete, and fish begin actively feeding on plankton) and post-larval stage (larval stage after absorption of yolk sac).

Long-term Survival--The proportion of the retained fish of a given test which were alive at the end of a 48-hour post-impingement holding period.

Pooled--Refers to the summing of the three replicate observations for each test such that the totals are treated as representing a single observation.

Proportion Bypassed--Refers to that proportion of the total number of fish released at the upstream end of the flume which are collected downstream at the test screens.

Retention--The nonpassage of fish through a test screen when forced against it by the water current.

Screening--Used interchangeably with retention.

Screen Opening--The clear opening distance in millimeters between any two parallel and adjacent wires of a screen. Only square opening woven wire screens were used in impinge-release testing. Slotted wedgewire screens were used in fish avoidance testing.

Test Duration--The elapsed time in minutes from when the first fish of a test group was observed impinged or entrained until the current was stopped.

APPENDIX A

IMPINGE-RELEASE CONCEPT
SUMMARY OF INITIAL FEASIBILITY STUDY

TEST FACILITY

The test facility provided for (1) instantly applying preselected velocities through a pressurized test chamber, (2) instantly reducing the velocity to zero, (3) interchanging screens of different material and mesh size, (4) collecting fish which passed through the test screen, and (5) safely removing fish retained in the test chamber.

The following experimental variables were examined during the first year.

Experimental Variables

Screen opening (mm)	0.5, 1.0, 1.3, 1.8, 2.5
Approach water velocity (cm/sec)	15, 31, 46, 58, (0.5, 1.0, 1.5, 1.9 fps)
Impingement duration (min)	0.5, 1, 2, 4, 8, 16

Fish species:

Common Name	Scientific Name
Jewelfish cichlid	Hemichromis bimaculatus
Threadfin shad (juveniles)	Dorosoma petenense
Golden shiner	Notemigonus crysoleucas
Fathead minnow	Pimephales promelas
White sucker	Catostomus commersoni
Channel catfish	Ictalurus punctatus
Striped bass	Morone saxatilis
Bluegill	Lepomis macrochirus
Smallmouth bass	Micropterus dolomieui
Largemouth bass	Micropterus salmoides
Walleye	Stizostedion vitreum

TEST PROCEDURES

A group of fish were placed in the test chamber, the chamber was pressurized, and a preselected velocity was applied for one of the preselected impingement

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durations. The larvae either impinged against the test screen or passed through it into a collection net. At the end of the test the velocity was reduced to zero, the chamber depressurized, and the impinged fish siphoned into a styrofoam cooler. Dead fish were removed and preserved; live fish were held for evaluating delayed test-induced mortality.

RESULTS

Two primary dependent variables were percentage of fish retained by the test screens and percentage survival of the retained or impinged fish. Table A-1 presents a summary of percentage of fish retained by screen opening size and average size of test fish.

Fish shape ranged among species from threadlike to stout. Body length alone was not a good indicator of percentage retention. Cross-sectional dimension was more important than length in determining whether or not the fish passed through the screen opening.

Average retention for the 0.5 mm opening screen was greater than 99 percent for the four species with the smallest body depths: walleye (1.4 mm), largemouth bass, (1.4 mm), white sucker (1.4 mm), and striped bass (1.0 mm). For screen openings larger than 0.5 mm, average percentage retention appeared to be largely dependent on average body depth. For each screen, the minimum mean body depth which resulted in essentially 100 percent retention was fairly well defined as follows:

Screen Opening (mm)	Body Depth (mm)
0.5	$\leq$0.7
1.0	1.8
1.3	2.4
1.8	2.8
2.5	4.6

A field study, in which fine-mesh screens were attached to a conventional vertical traveling screen, showed that the 0.5 mm opening screen impinged at least twice as many fish as the 1.0 and 2.0 mm opening screens.

Velocity did not significantly affect percentage retention for the two smallest openings, but was significant for the 1.3, 1.8, and 2.5 mm screens. This might indicate that at the smaller openings most of the fish tested were sufficiently large that velocity increments had no effect in "squeezing" the fish through the openings; whereas, for similar size fish but larger screen openings, increased velocity forced more fish through the openings.

Table A-2 and Figures A-1 and A-2 present a summary of percentage survival of the retained fish.

Survival of the control groups of each species gave some estimate of the mortality caused by handling and/or post-test holding. These data indicated that holding mortality was negligible (survival at 48 hours $\geq$ 90 percent) for all species except striped bass and walleye. For these fragile species, survival of the control groups was characterized by large variability.

TABLE A-1. PERCENT RETENTION OF FISH ON FINE-MESH SCREENS[1]

Species	Square mesh screen opening (mm)	Number of tests	Average retention (%)	95% confidence limits		Weighted mean size (mm) of all entrained and impinged test fish		
				Lower	Upper	Length	Width	Depth
Jewelfish cichlid	1.0	5	100.0	100.0	100.0	7.2	1.5	1.8
	1.3	6	68.1	58.7	76.8	7.3	1.6	1.8
Threadfin shad	0.5	19	100.0	100.0	100.0	39.5	4.2	8.9
	2.5	18	100.0	100.0	100.0	37.9	3.6	8.2
Golden shiner/ fathead minnow	1.0	12	97.0	93.2	99.3	11.7	1.5	1.8
	1.3	12	65.0	50.3	78.2	11.8	1.5	1.7
White sucker	0.5	12	99.9	99.8	100.0	14.1	1.2	1.4
	1.0	36	79.5	71.3	86.4	13.8	1.2	1.4
	1.3	19	30.6	16.3	47.2	13.6	1.3	1.4
Channel catfish	1.3	1	100.0	-	-	14.8	2.8	2.8
	1.8	24	99.2	97.7	99.9	15.7	3.0	2.8
	2.5	45	66.3	51.6	79.5	17.7	3.4	3.3
Striped bass	0.5	102	99.1	98.7	99.4	6.2	0.7	1.0
	1.0	66	29.3	24.1	34.9	6.6	0.9	1.0
	1.3	14	24.0	8.0	44.8	7.7	1.0	1.3
Bluegill	1.3	1	100.0	-	-	13.8	2.0	2.9
	1.8	13	99.4	97.6	100.0	14.3	2.2	3.0
	2.5	16	72.7	58.5	84.9	14.3	2.1	2.9
Smallmouth bass	1.3	12	99.9	99.6	100.0	10.8	2.0	2.5
	1.8	24	82.4	66.4	94.0	12.0	2.1	2.7
	2.5	9	30.6	9.2	57.8	13.4	2.3	2.9

TABLE A-1. (continued)

Species	Square mesh screen opening (mm)	Number of tests	Average retetention (%)	95% confidence limits		Weighted mean size (mm) of all entrained and impinged test fish		
				Lower	Upper	Length	Width	Depth
Largemouth bass	0.5	17	99.5	98.5	100.0	6.8	1.1	1.4
	1.0	26	84.7	71.8	94.2	7.7	1.3	1.6
	1.3	39	80.4	71.1	88.2	8.9	1.6	1.9
	1.8	9	38.2	17.6	61.4	10.3	1.7	2.2
Walleye	0.5	12	99.7	98.6	100.0	9.6	1.1	1.4
	1.0	18	89.7	84.5	94.0	9.8	1.3	1.5
	1.3	16	11.0	8.2	14.3	10.3	1.3	1.6

1. Current velocities (0.5-1.5 fps; 15.2-46.7 cm/s) and test durations (0.5-16.0 min) were combined for each species and screen opening.

TABLE A-2. MEAN PERCENT SURVIVAL OF FISH IMPINGED ON FINE-MESH SCREENS (SCREEN OPENINGS AND VELOCITIES COMBINED) AND CONTROL GROUPS.

Species	Hours Fish Held After Test	Test Duration (minutes)						Mean Survival[1] of Controls (%)	L[2]	U[2]
		.5	1	2	4	8	16			
Jewelfish cichlid	0	65	81	91	85	90	43	NA	-	-
	6-12	53	65	83	76	69	30	100	-	-
	24	53	59	83	76	69	30	100	-	-
	48	53	59	83	76	69	30	100	-	-
Threadfin shad	0	100	100	100[3]	98	75	55	NA		
	6-12	99	97	85	72	44	26	100	-	-
	24	97	96	77	69	44	21	98	-	-
	48	95	93	74	69	43	20	98	-	-
Golden shiner/ Fathead minnow	0	99	95	91	89	90	89	NA		
	6-12	94	92	90	87	86	81	99	-	-
	24	94	91	90	87	86	81	99	-	-
	48	94	90	90	84	86	79	99	-	-
White sucker	0	99	96	99	90	95	74	NA		
	6-12	97	94	98	84	80	40	100	100	100
	24	97	93	98	84	80	37	100	100	100
	48	97	92	98	80	77	36	100	100	100
Channel catfish	0	100[3]	99	100	100[3]	100[3]	97	NA		
	6-12	100[3]	99	100	100[3]	99	90	99.8	98	100
	24	100[3]	99	100	99	99	88	99.5	97	100
	48	100[3]	98	100	99	99	88	99.5	97	100
Striped bass	0	79	85	80	72	51	7	NA		
	6-12	52	52	46	37	20	1	82	70	92
	24	35	36	34	22	13	<1	56	38	73
	48	22	25	27	18	10	<1	44	30	61
Bluegill	0	100	100	100[3]	99	97	96	NA		
	6-12	100	100[3]	100[3]	99	97	96	100	-	-
	24	100	100[3]	100[3]	99	97	96	100	-	-
	48	100	100[3]	100[3]	99	97	96	99	-	-
Smallmouth bass	0	100[3]	99	99	98	100[3]	100[3]	NA		
	6-12	99	99	98	98	100[3]	98	100	100	100
	24	99	99	98	98	100[3]	98	100	100	100
	48	98	88	98	97	98	96	100	100	100

TABLE A-2. (Continued)

Species	Hours Fish Held After Test	Test Duration (minutes)						Mean Survival[1] of Controls (%)	L[2]	U[2]
		.5	1	2	4	8	16			
Largemouth bass	0	93	96	94	93	93	70	NA		
	6-12	88	90	89	82	83	62	99	97	100
	24	79	85	87	71	75	54	96	91	99
	48	74	81	83	61	71	52	93	88	97
Walleye	0	90	79	75	74	35	9	NA		
	6-12	66	60	53	42	9	2	84	-	-
	24	65	52	51	38	9	2	74	-	-
	48	63	48	49	38	9	2	71	-	-

1. 95 percent confidence limits calculated only if n >3.
2. L and U represent lower and upper 95 percent confidence limits, respectively, about the mean control survivals.
3. Average survival greater than 99.49 but less than 100.00.

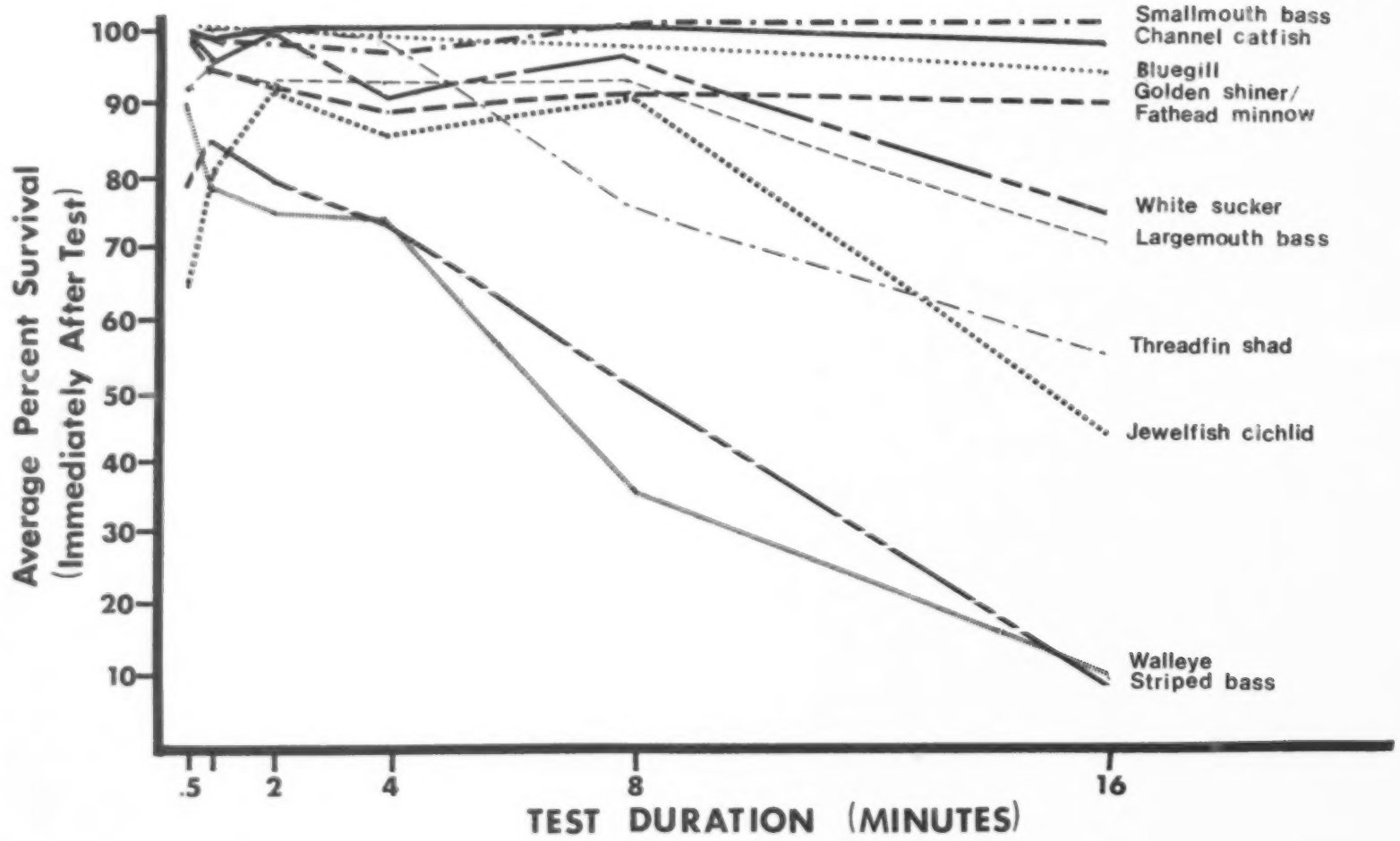

Figure A-1. Relationship of average immediate post-test survival of fish impinged on fine mesh screens to test duration. Fish sizes, screen openings, and velocities were combined.

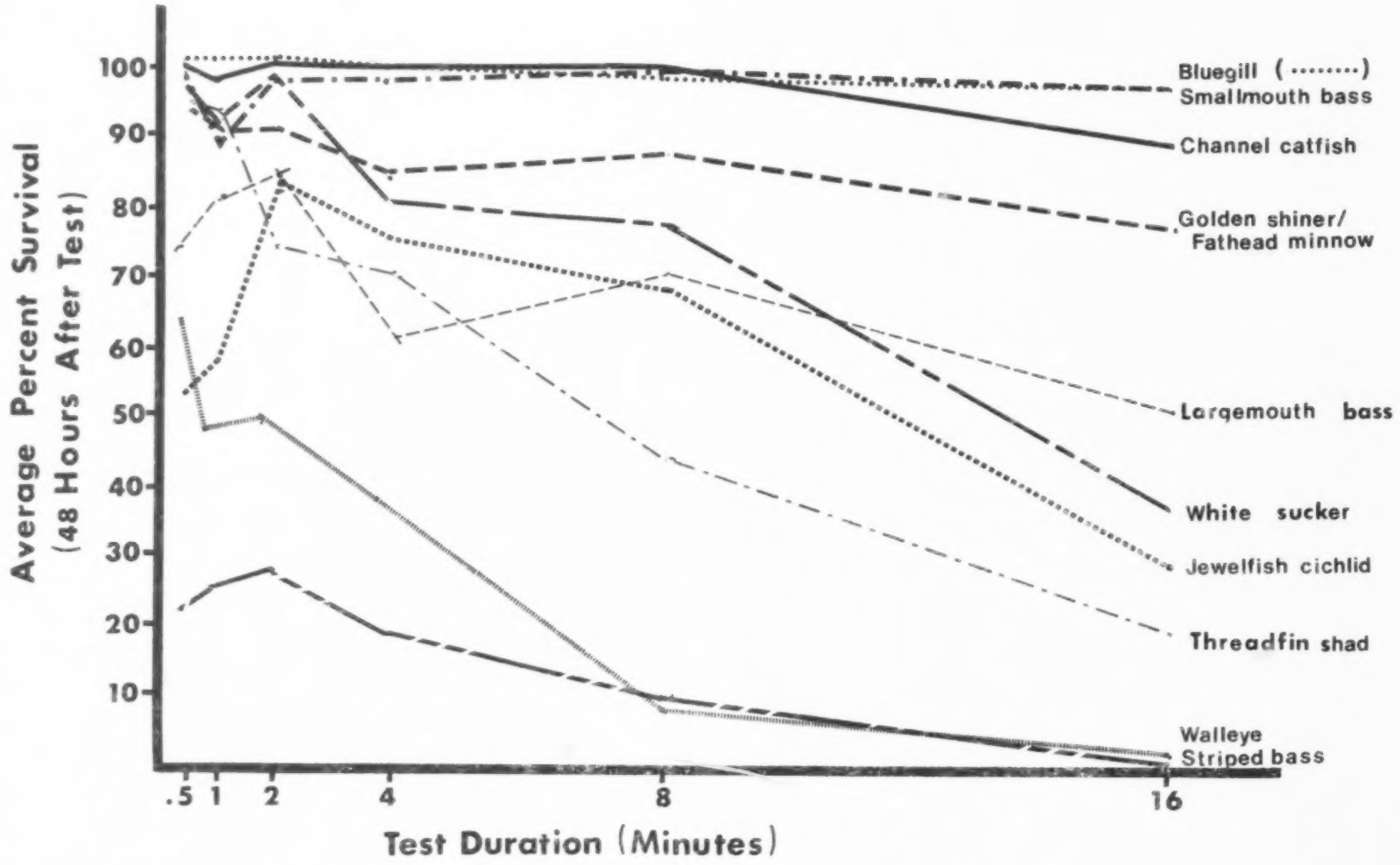

Figure A-2. Relationship of average long-term (48-hour survival of fish impinged on fine mesh screens to test duration. Fish sizes, screen openings, and velocities were combined.

Average survival following impingement varied greatly among species, ranging from 100 percent to less than 1 percent. Two species (smallmouth bass, bludgill) showed high survival under practically all test conditions.

Impingement duration was the predominant variable affecting initial and long-term survival and showed a strong inverse relationship to survival for all taxa which responded to the test conditions.

For five taxa which showed fairly high average survival, (juvenile threadfin shad, mixed minnows, white sucker, bluegill, largemouth bass) approach velocity showed a significant inverse relationship to survival. Generally, larger fish showed better survival than smaller fish of the same species.

CONCLUSIONS

The results of the initial laboratory and field study demonstrated the relationships of percentage retention to screen opening size and the remaining test variables. The relationships of survival of the screened fish to the test variables were also well defined within the range of species and sizes tested.

Accurately predicting survival of all species and sizes of larvae which would be retained on a prototype screen was not possible owing to the (1) large differences in size and hardiness that would be found among species in the natural environment and (2) additional sources of mechanical handling mortality associated with screens used.

APPENDIX B

FISH AVOIDANCE CONCEPT
SUMMARY OF INITIAL TEST YEAR

NUMERICAL ANALYSES

Table B-1 outlines the combinations of test variables used for each species. A replicated goodness-of-fit procedure was found to be applicable to the analysis of the first year's experimental question. The "G" statistical parameter was selected because of ease of calculation and because it allowed a precise determination of within-replicate variability or "heterogeneity" (Sokal and Rohlf 1969).

The expected proportions bypassed and entrapped were determined by the unique bypass-slot velocity combination for each test. Differences between the horizontal and vertical orientations were analyzed by comparing the observed proportions of fish bypassed (pooled over replicate tests) with a paired t-test (Ostle 1963). Figures B-1 to B-8 present the results for each species tested.

Since the proportion of water entrained among bypass-slot velocity combinations was not constant in this experiment, direct examination of the proportion of fish bypassed as a means of comparing fish response among slot velocities and between bypass velocities was not meaningful. Therefore a variable, which was adjusted for the different expected entrainment values, was calculated using the formula:

$$Pr = \frac{Pb - \hat{Pb}}{1 - \hat{Pb}}$$

where Pr = "relative bypass," Pb = observed pooled proportion of fish bypassed, and $\hat{Pb}$ = expected proportion bypassed (based on proportion of total flow entrained through the screen for a given bypass-slot velocity combination). This variable (Pr) represents relative bypass as the ratio of the observed bypass ($Pb - \hat{Pb}$) to the maximum possible bypass described by ($1 - \hat{Pb}$). Thus, a score of 1.00 for any given test would indicate that all of the larvae had bypassed the screen, and a score of 0.00 was obtained when the observed proportion bypassed was equal to the expected proportion. A negative value indicated that a larger proportion was entrapped than was predicted by the expected proportion. However, since relative bypass was not bounded on the negative scale, the magnitude of a negative value had little comparative meaning. Figures B-9 to B-20 graphically present this relationship for the species tested.

TABLE B-1. SPECIES AND VARIABLES TESTED DURING THE FIRST YEAR'S EXPERIMENT.

Species	VARIABLES											
	Slot Size			Slot Orientation		Bypass Velocity cm/s				Slot Velocity cm/s		
	0.5 mm	1.0 mm	2.0 mm	Horiz	Vert	7.5	15	30.5	61.0	7.5	15.0	22.9
Largemouth Bass	X		X	X	X		X	X	X	X	X	X
Bluegill			X	X	X		X	X	X		X	X
Channel Catfish		X	X	X	X		X	X	X	X	X	X
Striped Bass (test 1)	X	X	X	X	X	X	X	X	X	X	X	X
Striped Bass (test 2)		X	X	X	X		X	X	X	X	X	X
Muskellunge			X	X	X	X	X	X			X	
Walleye	X	X	X	X	X	X	X	X	X	X	X	X
Smallmouth Bass		X	X	X	X		X	X	X	X	X	X

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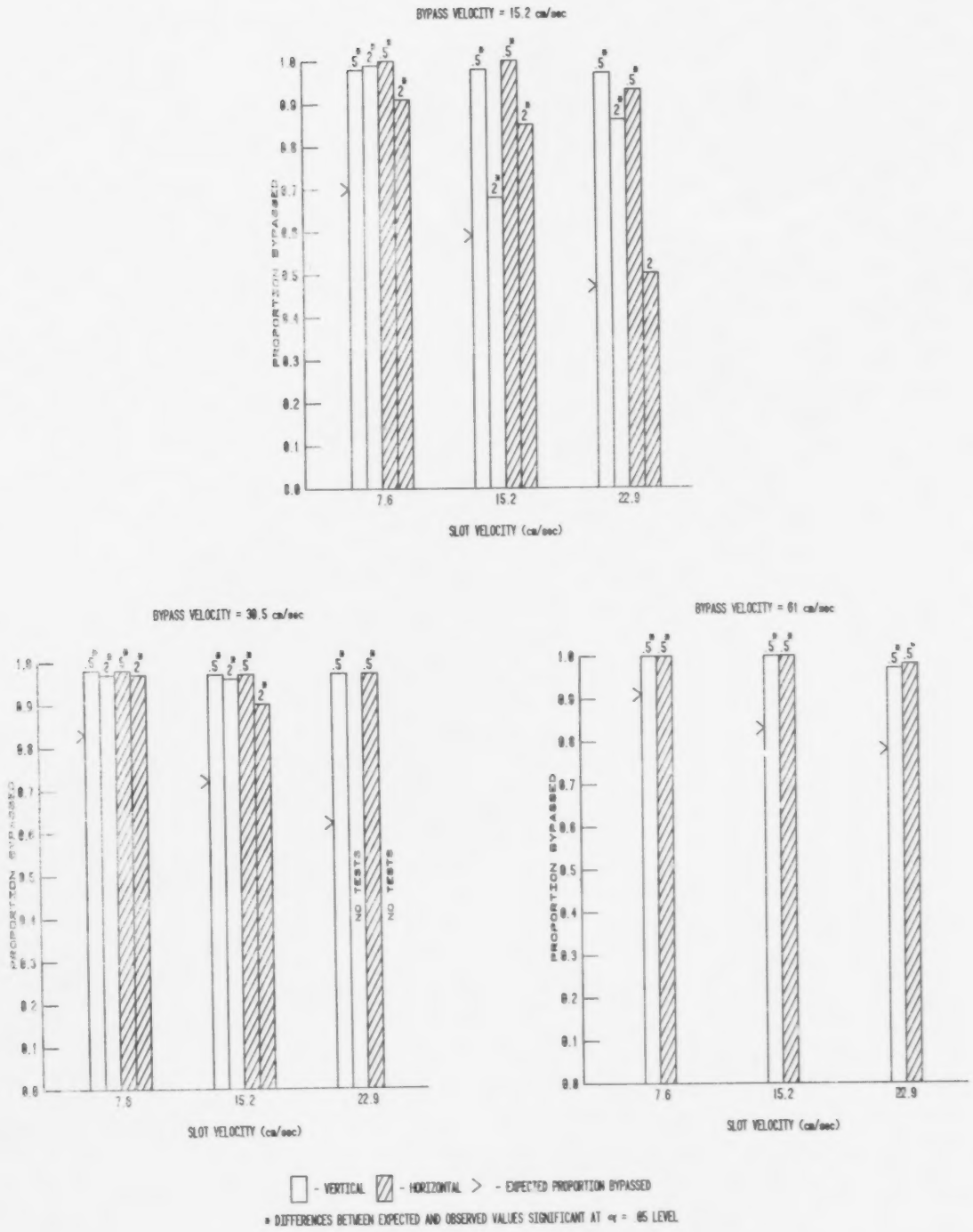

BYPASS VELOCITY = 15.2 cm/sec
PROPORTION BYPASSED
SLOT VELOCITY (cm/sec)
7.6
15.2
22.9
BYPASS VELOCITY = 30.5 cm/sec
NO TESTS
BYPASS VELOCITY = 61 cm/sec
- VERTICAL - HORIZONTAL > - EXPECTED PROPORTION BYPASSED
* DIFFERENCES BETWEEN EXPECTED AND OBSERVED VALUES SIGNIFICANT AT α = .05 LEVEL

Figure B-1. Proportion of largemouth bass bypassed by slot width (denoted in mm above each bar) and screen orientation for each slot and bypass velocity.

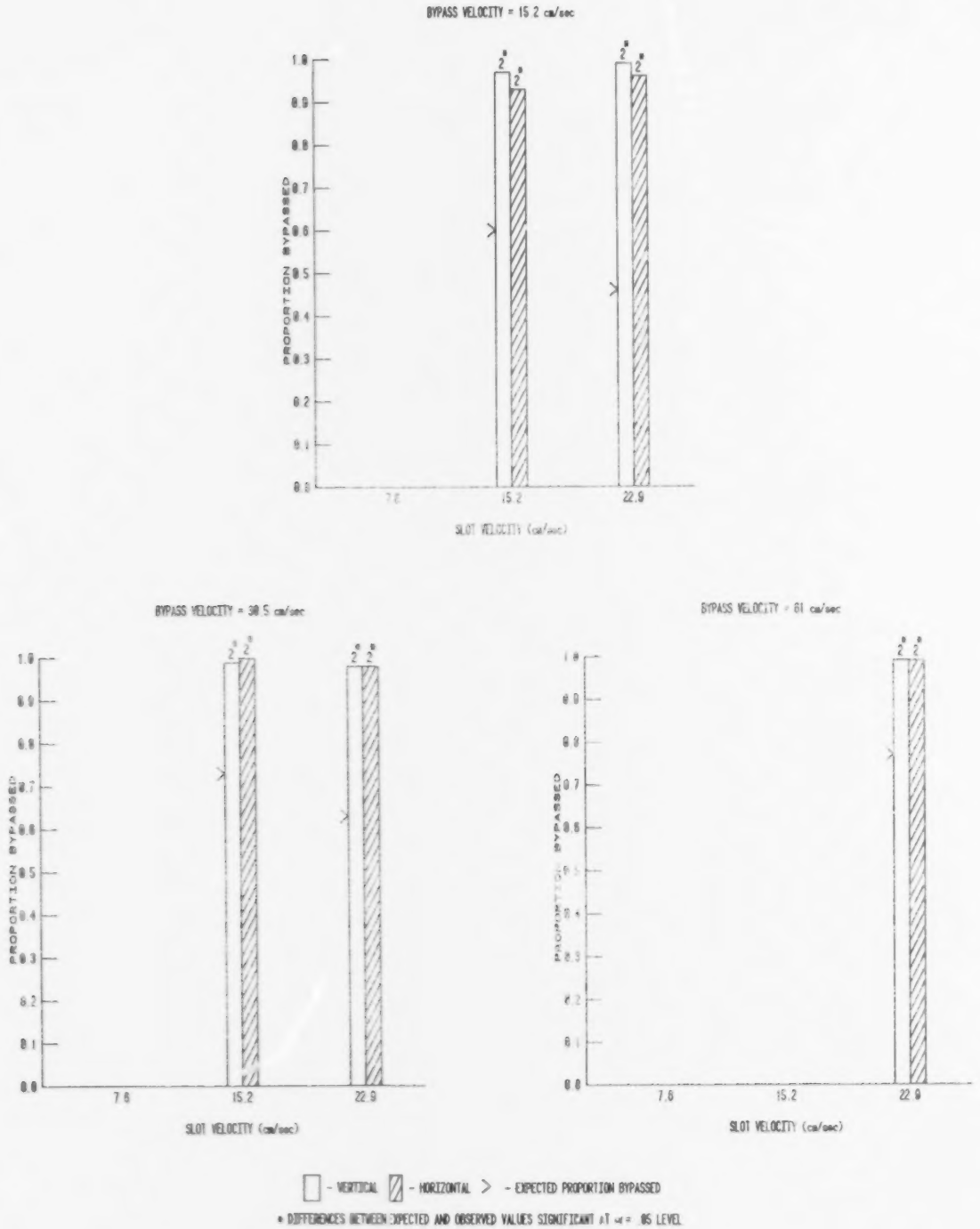


Figure B-2. Proportion of bluegill bypassed by slot width (denoted in mm above each bar) and screen orientation for each slot and bypass velocity.

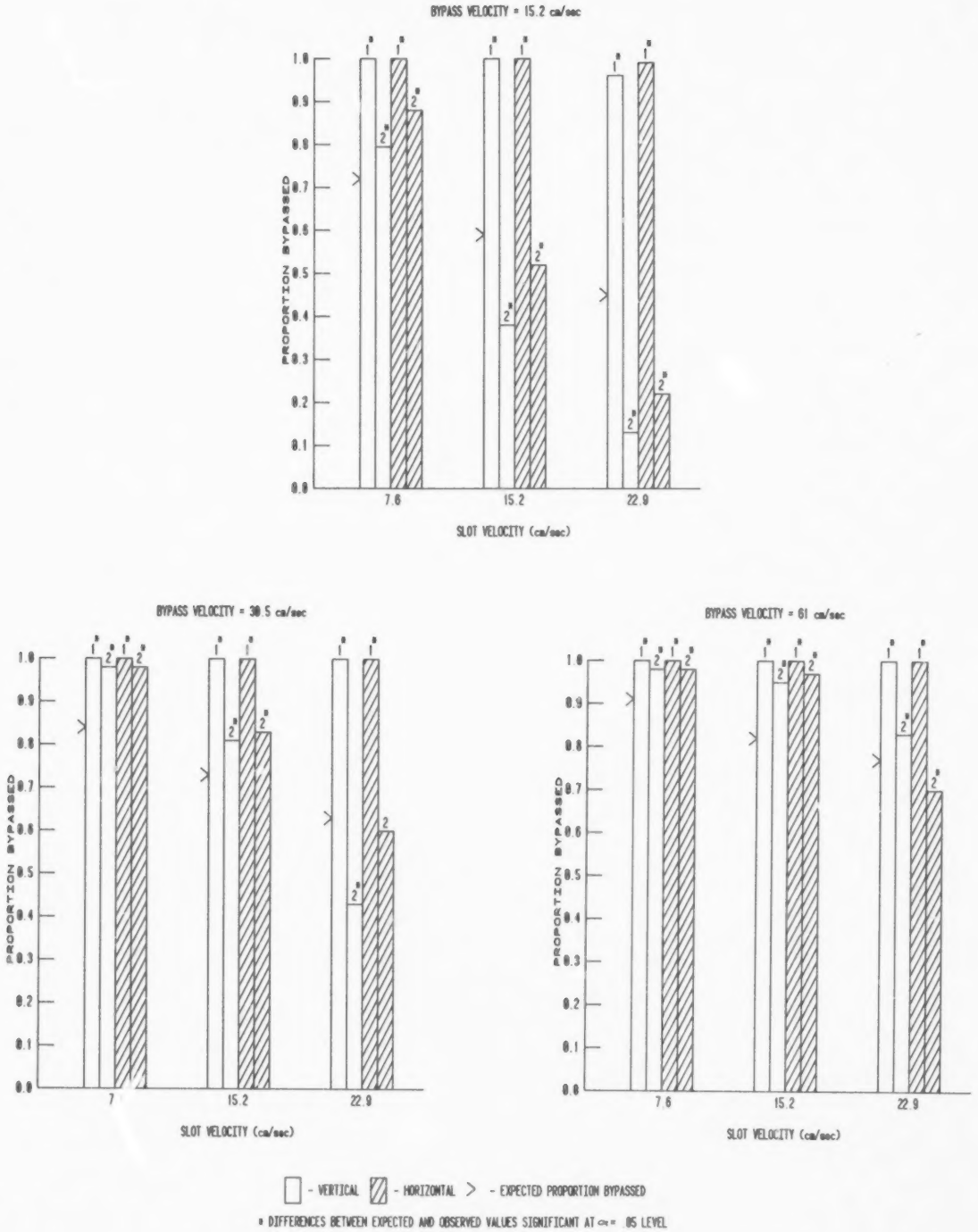
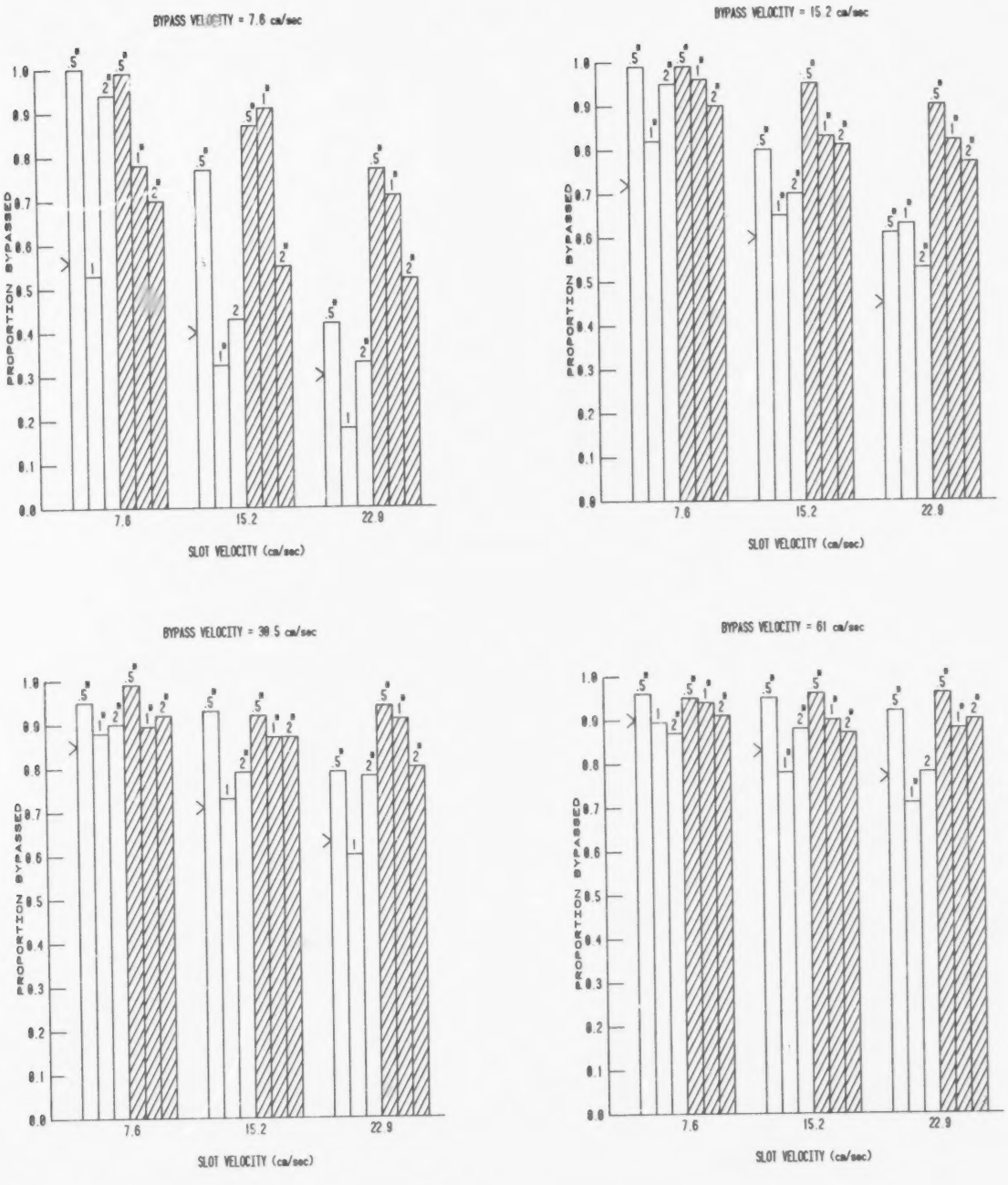


Figure B-3. Proportion of channel catfish bypassed by slot width (denoted in mm above each bar) and screen orientation for each slot and bypass velocity.



*Denotes differences between expected and observed values significant at $\alpha = 0.05$ level.

Figure B-4. Proportion of striped bass bypassed by slot width (denoted in mm above each bar) and screen orientation for each slot and bypass velocity.
Test 1

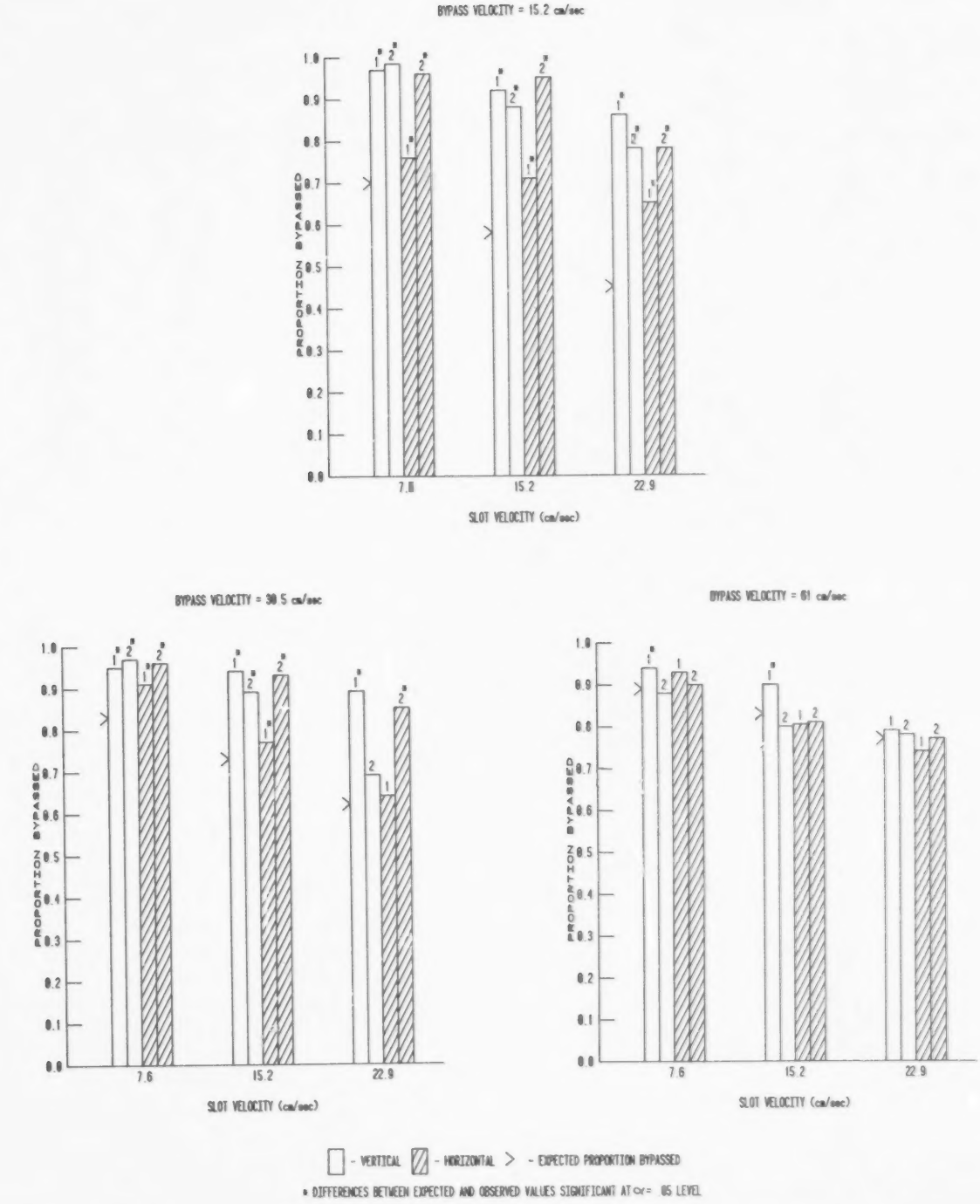

BYPASS VELOCITY = 15.2 cm/sec
PROPORTION BYPASSED
7.6
15.2
22.9
SLOT VELOCITY (cm/sec)
BYPASS VELOCITY = 30.5 cm/sec
BYPASS VELOCITY = 61 cm/sec
- VERTICAL - HORIZONTAL > - EXPECTED PROPORTION BYPASSED
* DIFFERENCES BETWEEN EXPECTED AND OBSERVED VALUES SIGNIFICANT AT α= .05 LEVEL

Figure B-5. Proportion of striped bass bypassed by slot width (denoted in mm above each bar) and screen orientation for each slot and bypass velocity.

Test 2

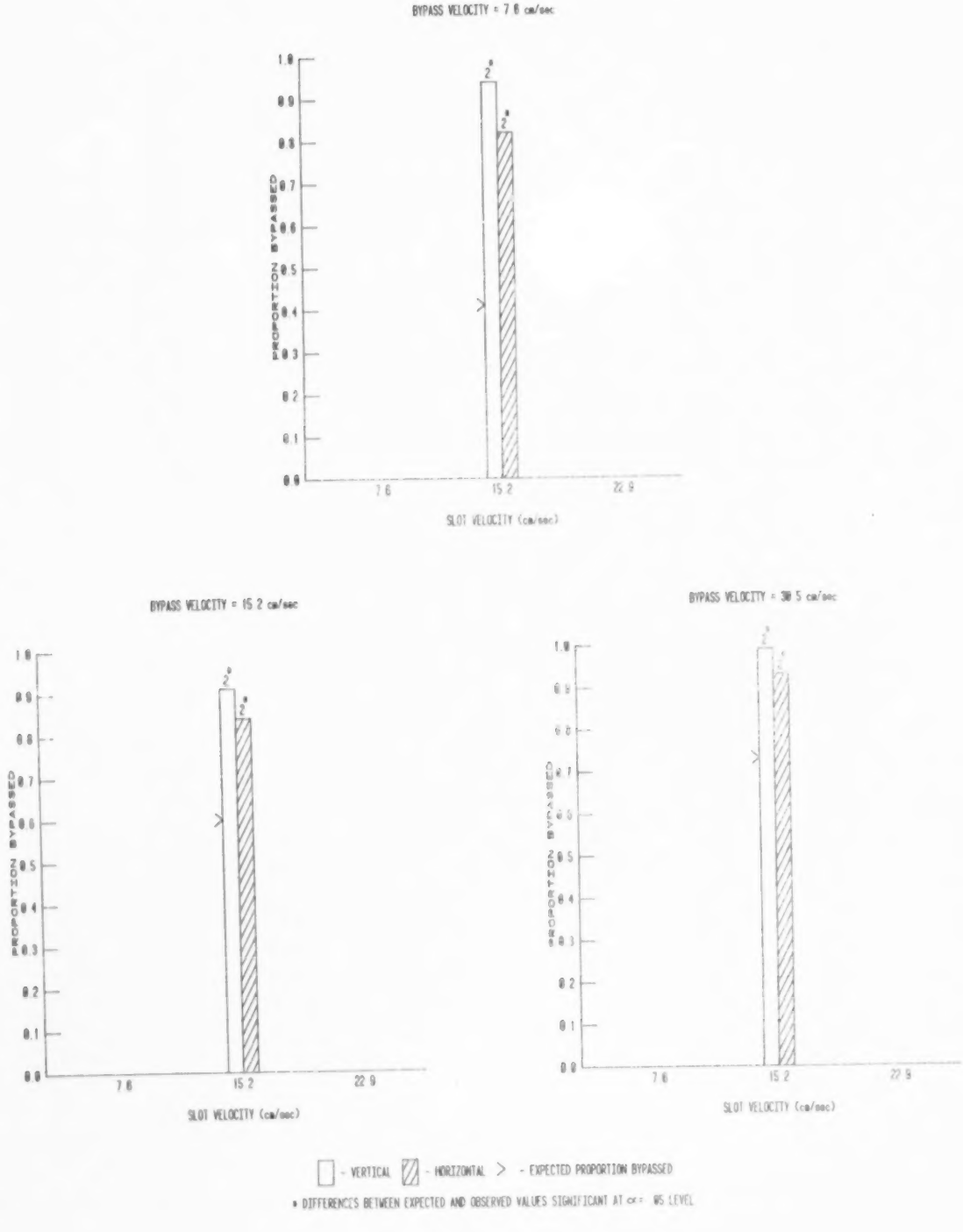
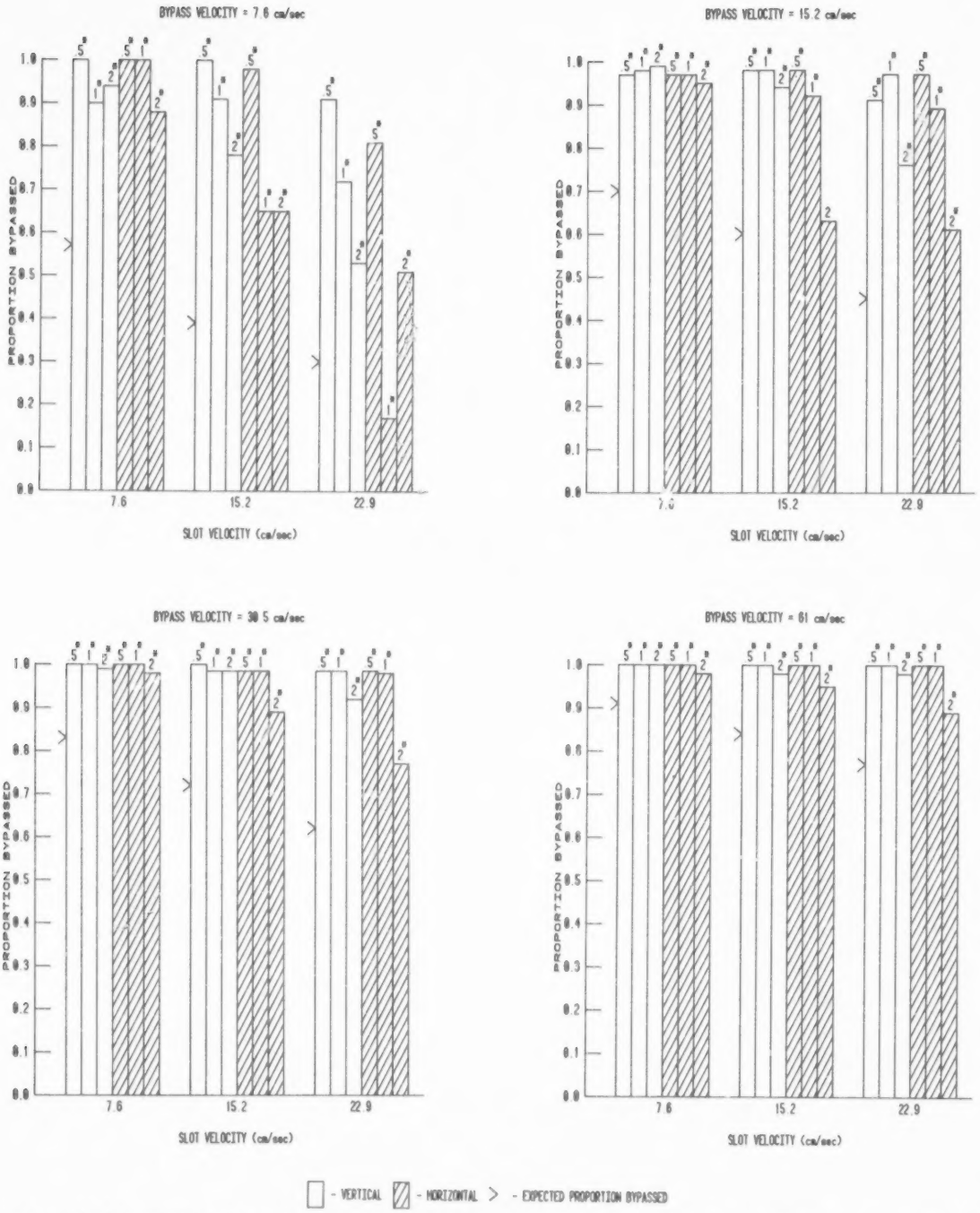
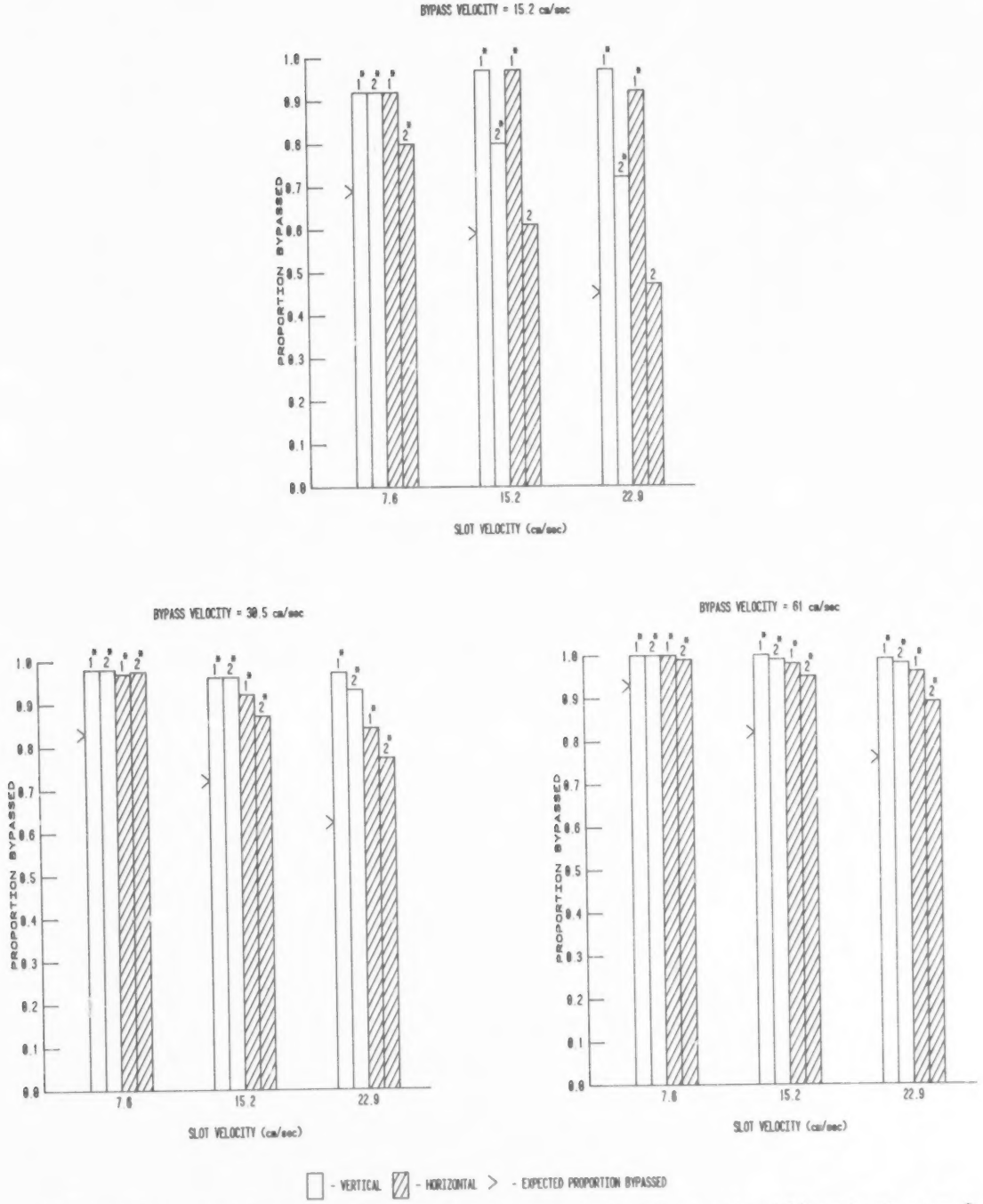


Figure B-6. Proportion of muskellunge bypassed by slot width (denoted in mm above each bar) and screen orientation for each slot and bypass velocity.



*Denotes differences between expected and observed values significant at $\alpha = 0.05$.

Figure B-7. Proportion of walleye bypassed by slot width (denoted in mm above each bar) and screen orientation for each slot and bypass velocity.



*Denotes differences between observed and expected values significant at $\alpha = 0.05$.

Figure B-8. Proportion of smallmouth bass bypassed by slot width (denoted in mm above each bar) and screen orientation for each slot and bypass velocity.

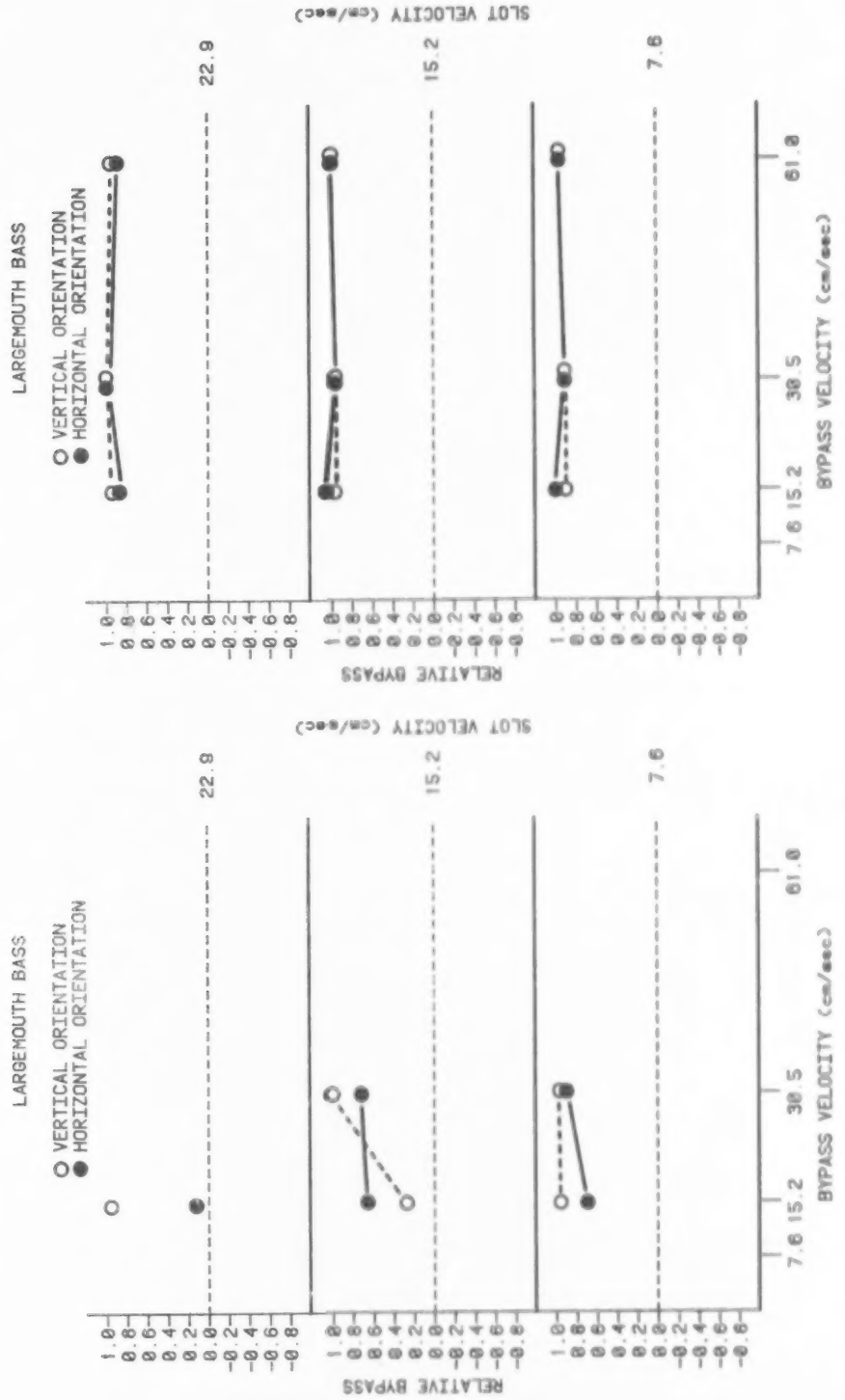


Figure B-9. Results of larval fish screening investigations ("fish avoidance" concept): relationship of relative bypass to bypass and slot velocity for largemouth bass.

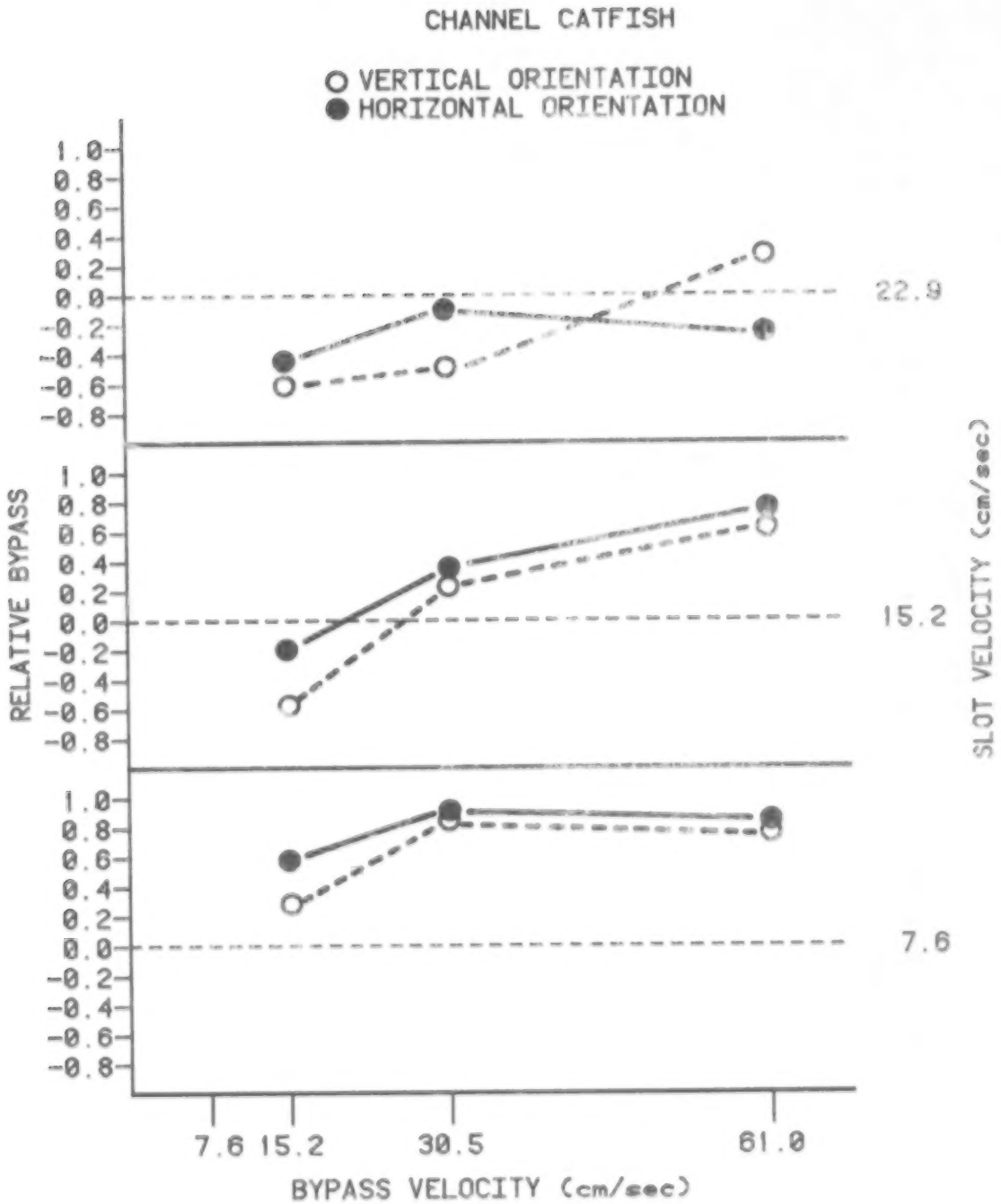


Figure B-10. Results of larval fish screening investigations ("fish avoidance" concept): relationship of relative bypass to bypass and slot velocity for channel catfish. Slot width of screen - 2.0 mm.

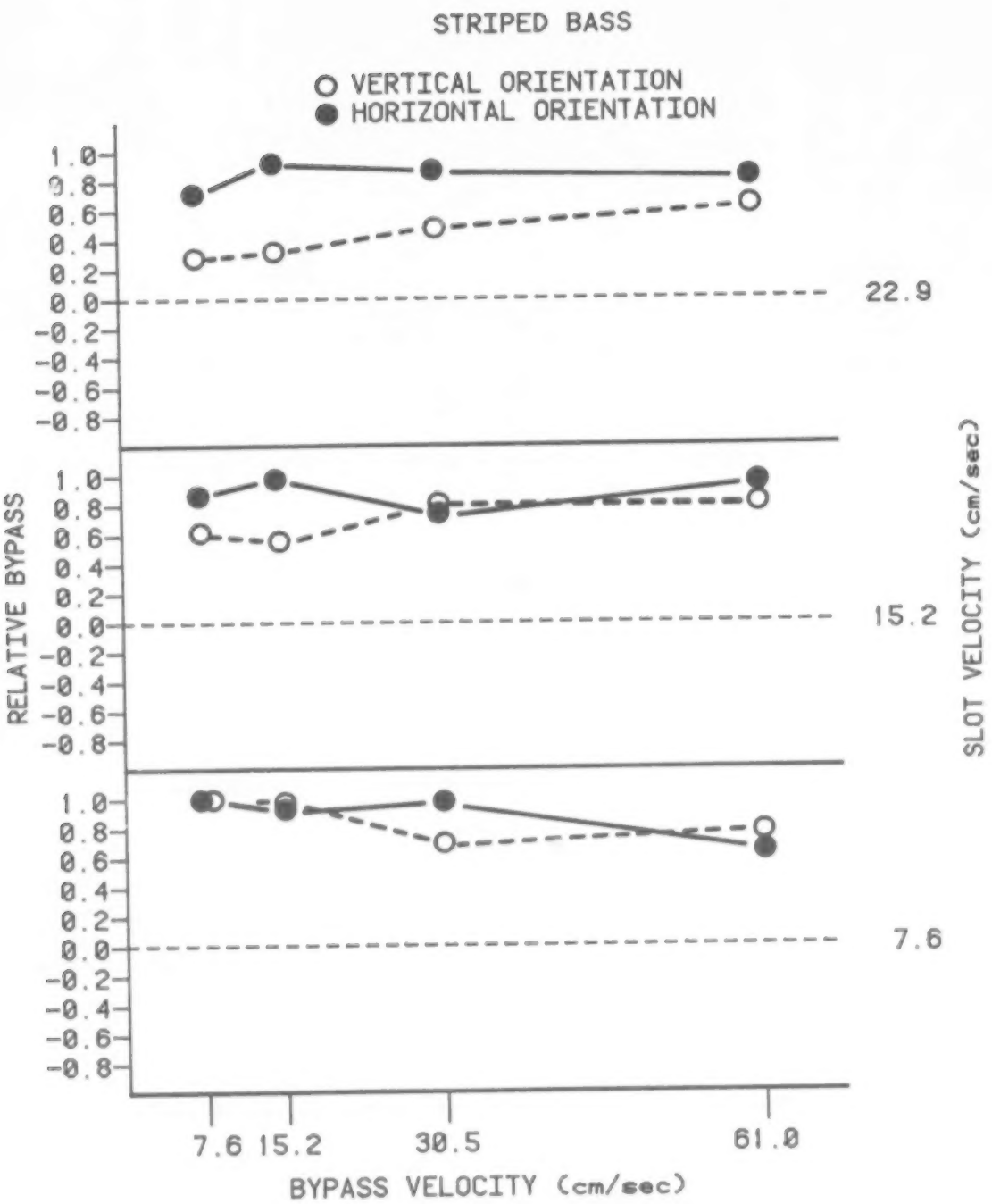


Figure B-11. Results of larval fish screening investigations ("fish avoidance" concept): relationship of relative bypass to bypass and slot velocity for striped bass. Slot width of the screen = 0.5 mm. Test 1.

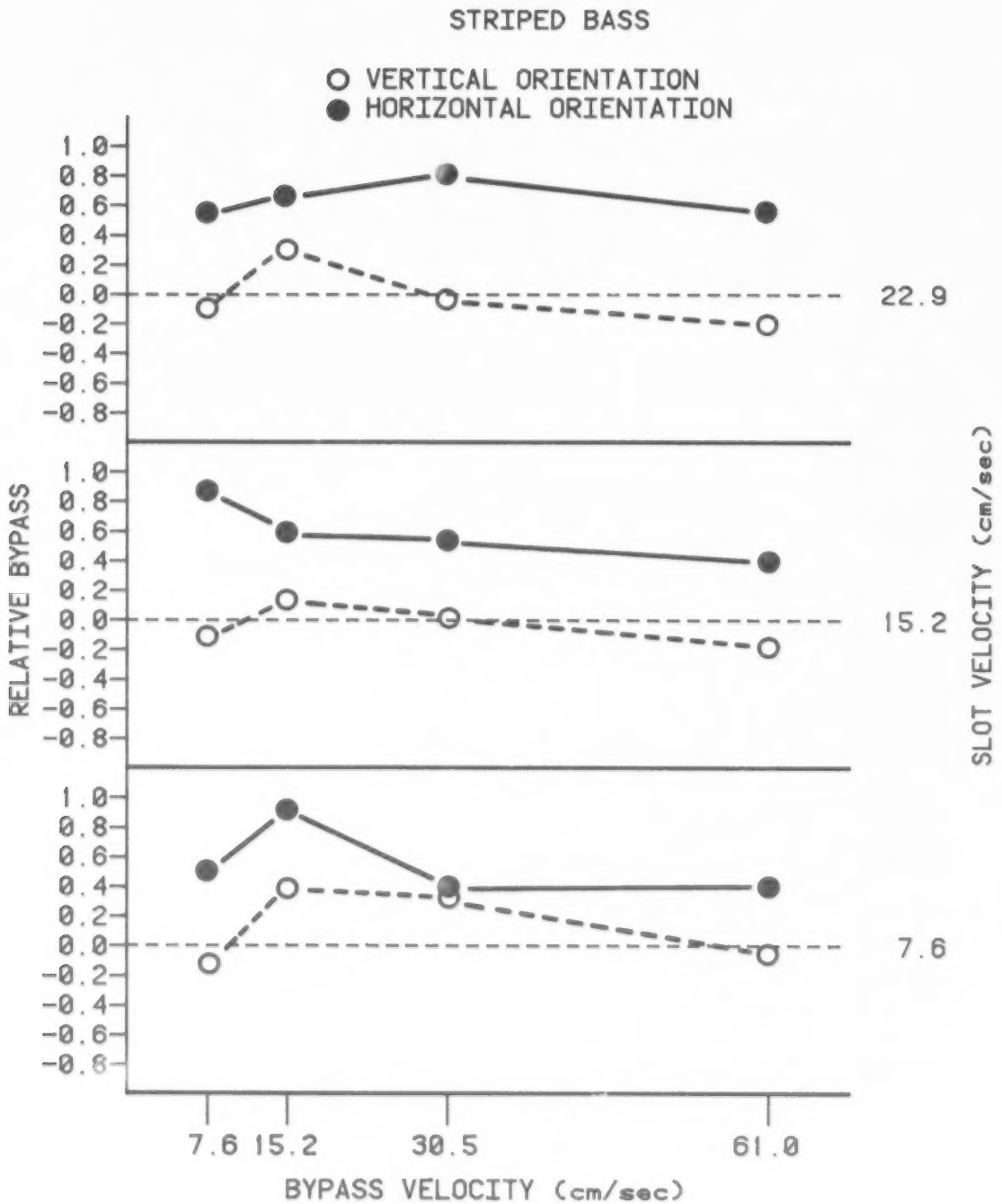


Figure B-12. Results of larval fish screening investigations ("fish avoidance" concept): relationship of relative bypass to bypass and slot velocity for striped bass. Slot width of the screen = 1.0 mm. Test 1.

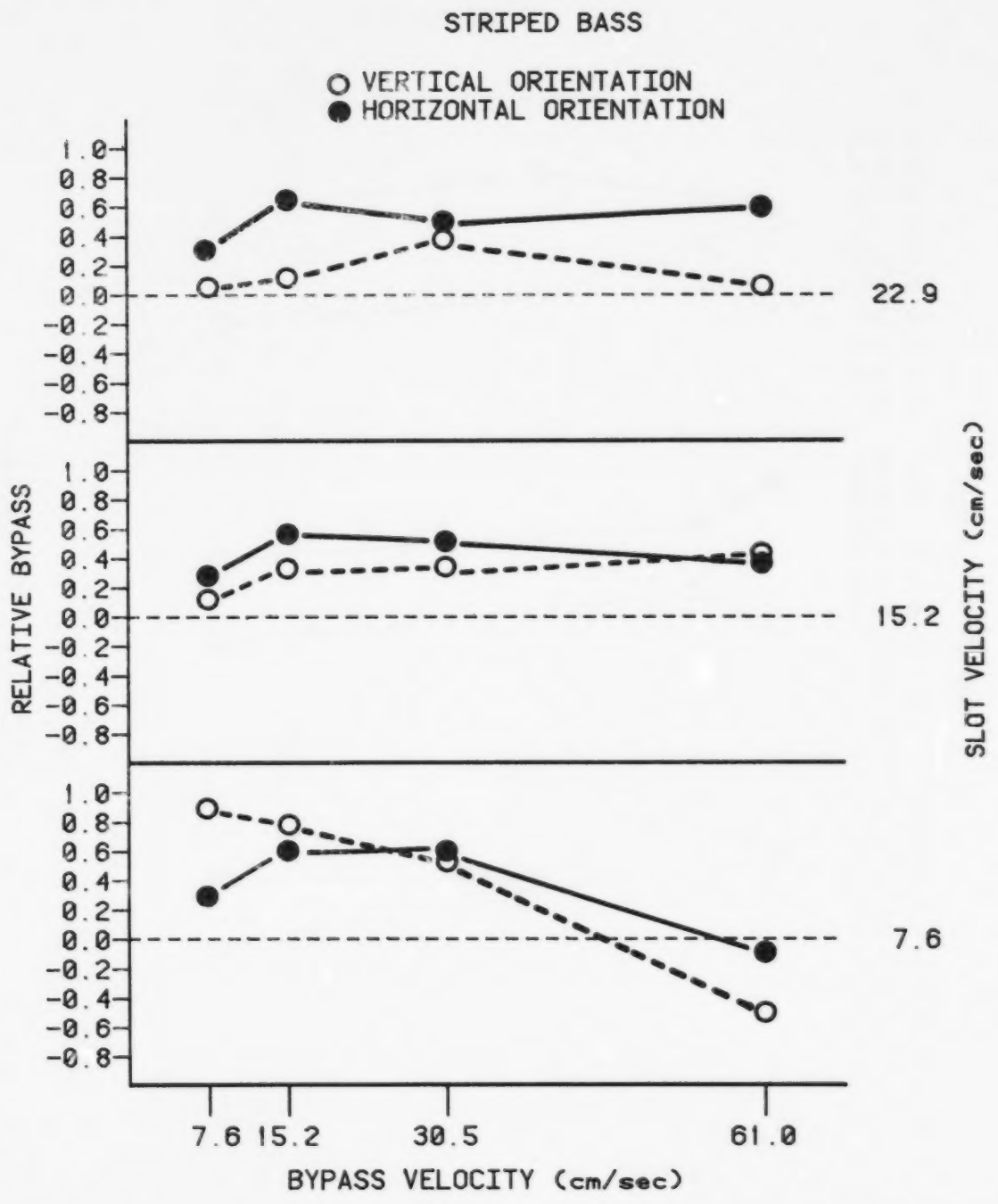


Figure B-13. Results of larval fish screening investigations ("fish avoidance" concept): relationship of relative bypass to bypass and slot velocity for striped bass. Slot width of the screen = 2.0 mm. Test 1.

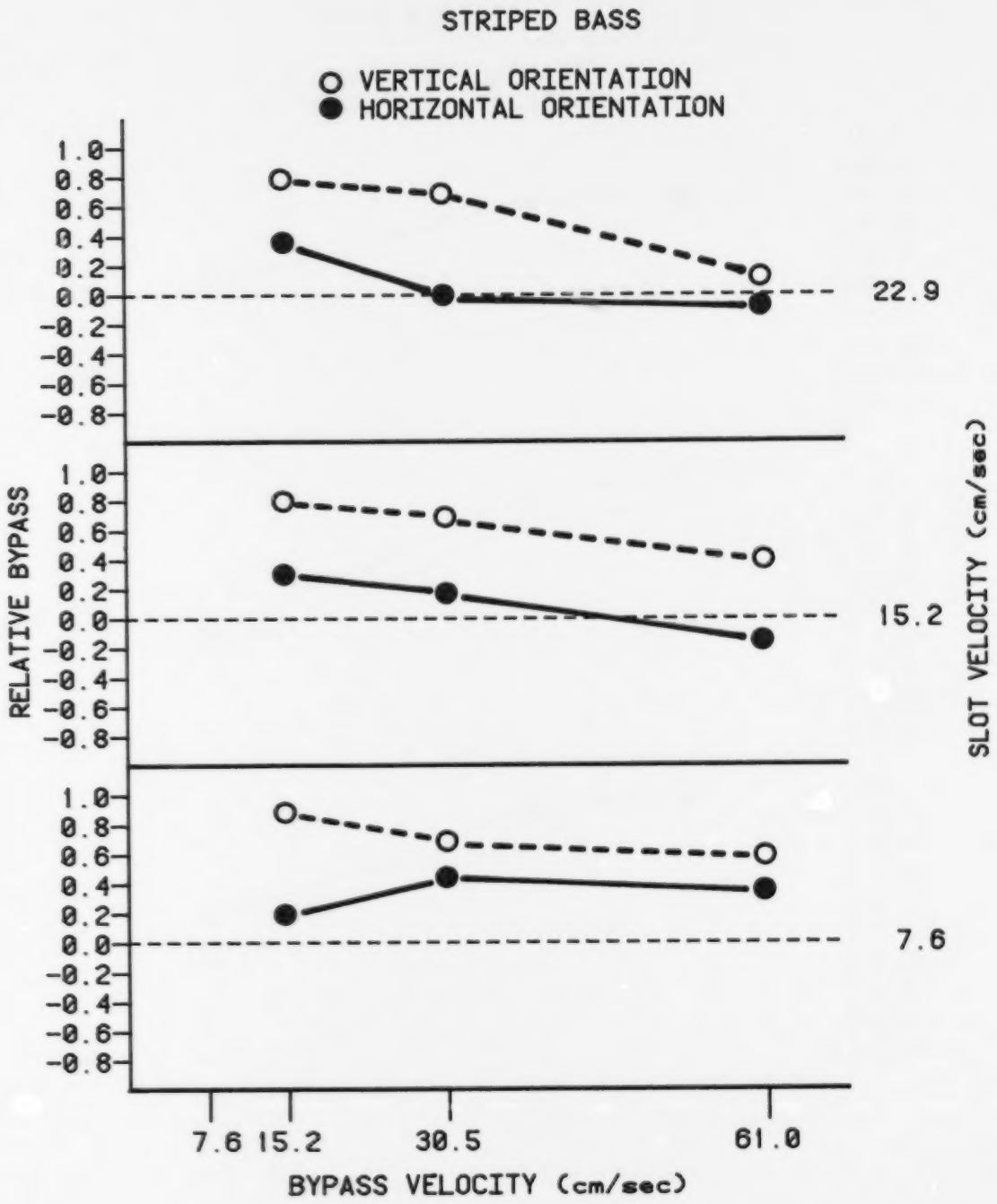


Figure B-14. Results of larval fish screening investigations ("fish avoidance" concept): relationship of relative bypass to bypass and slot velocity for striped bass. Slot width of the screen = 1.0 mm. Test 2.

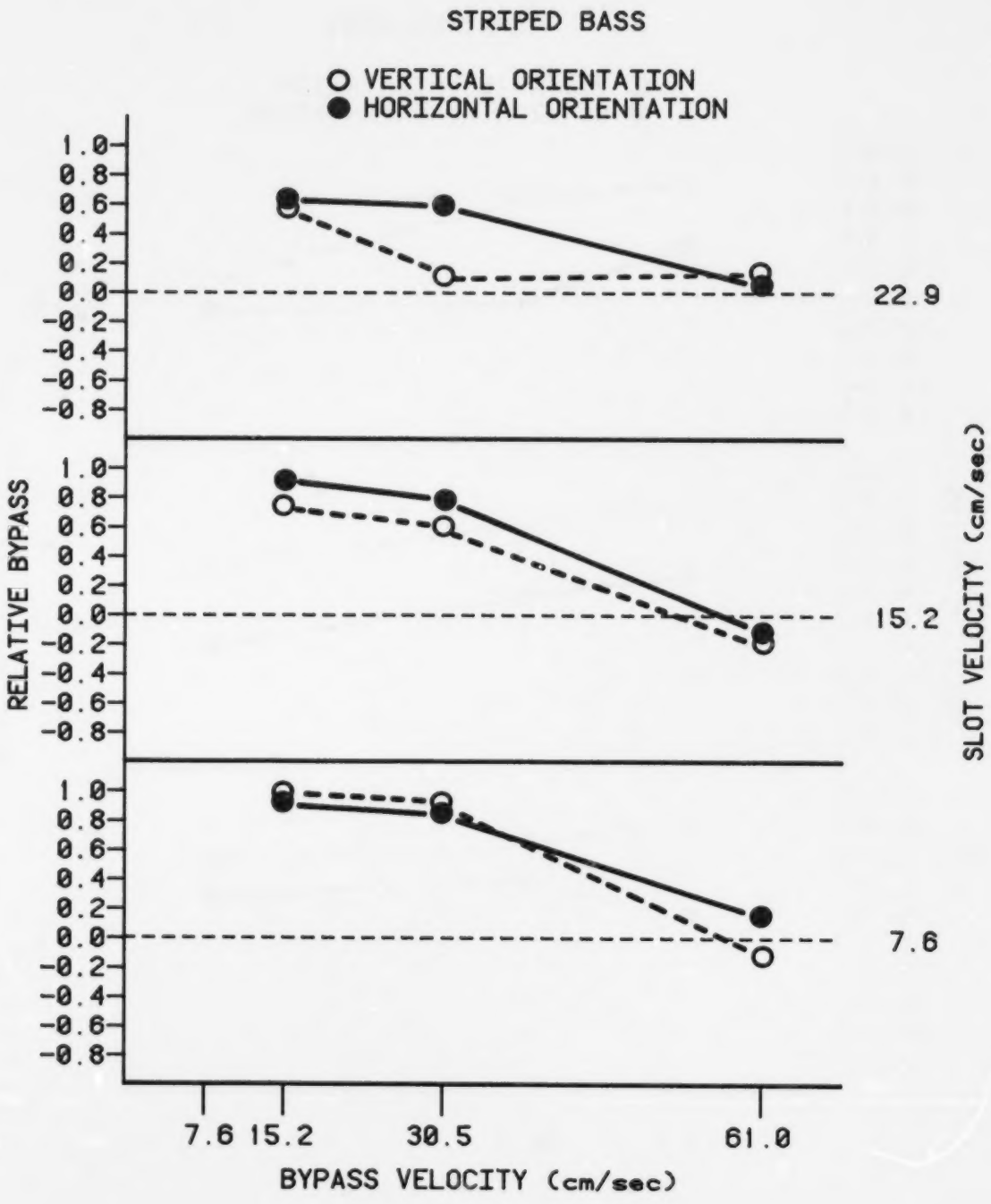


Figure B-15. Results of larval fish screening investigations ("fish avoidance" concept): relationship of relative bypass to bypass and slot velocity for striped bass. Slot width of the screen = 2.0 mm. Test 2.

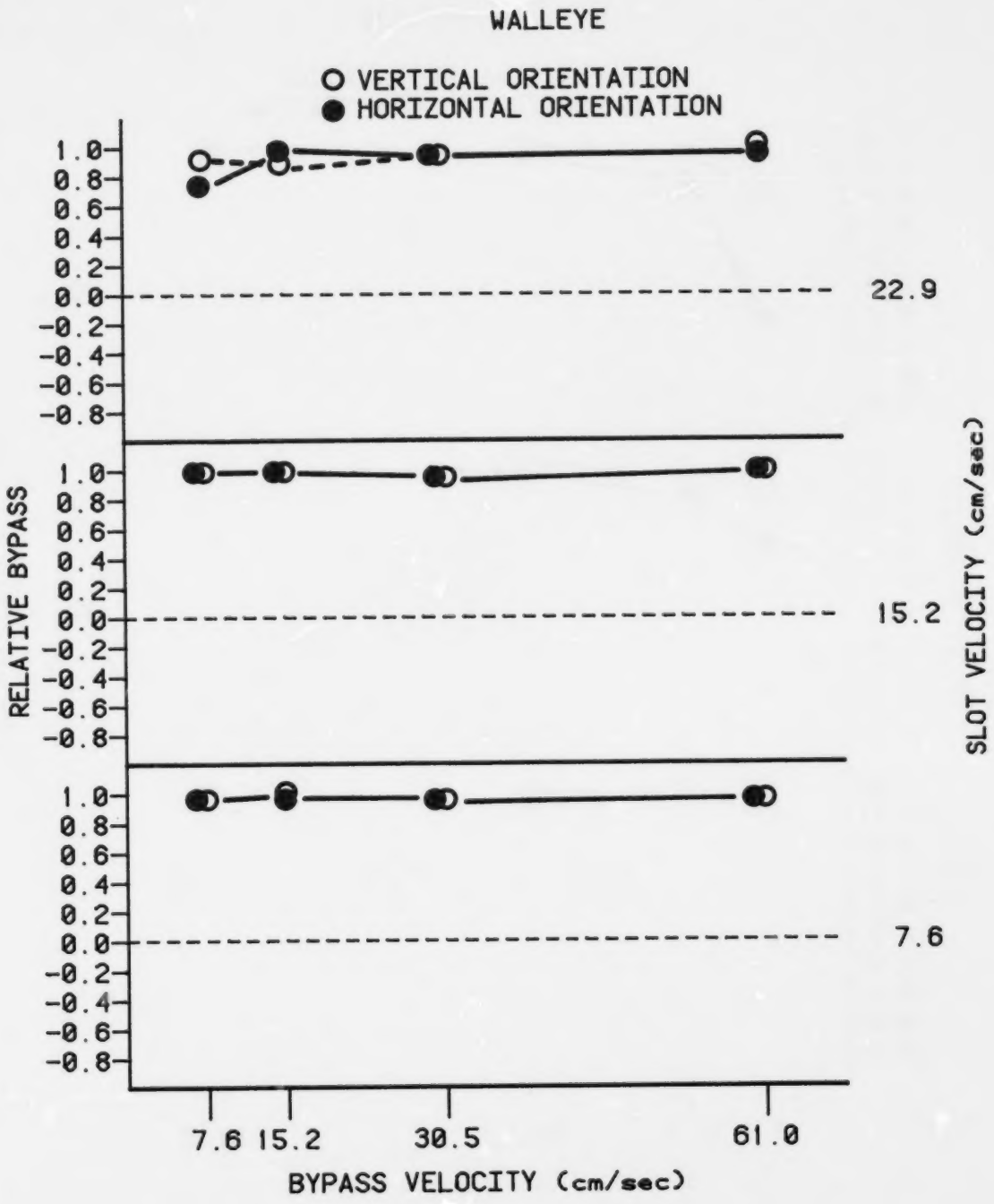


Figure B-16. Results of larval fish screening investigations ("fish avoidance" concept): relationship of relative bypass to bypass and slot velocity for walleye. Slot width of the screen = 0.5 mm.

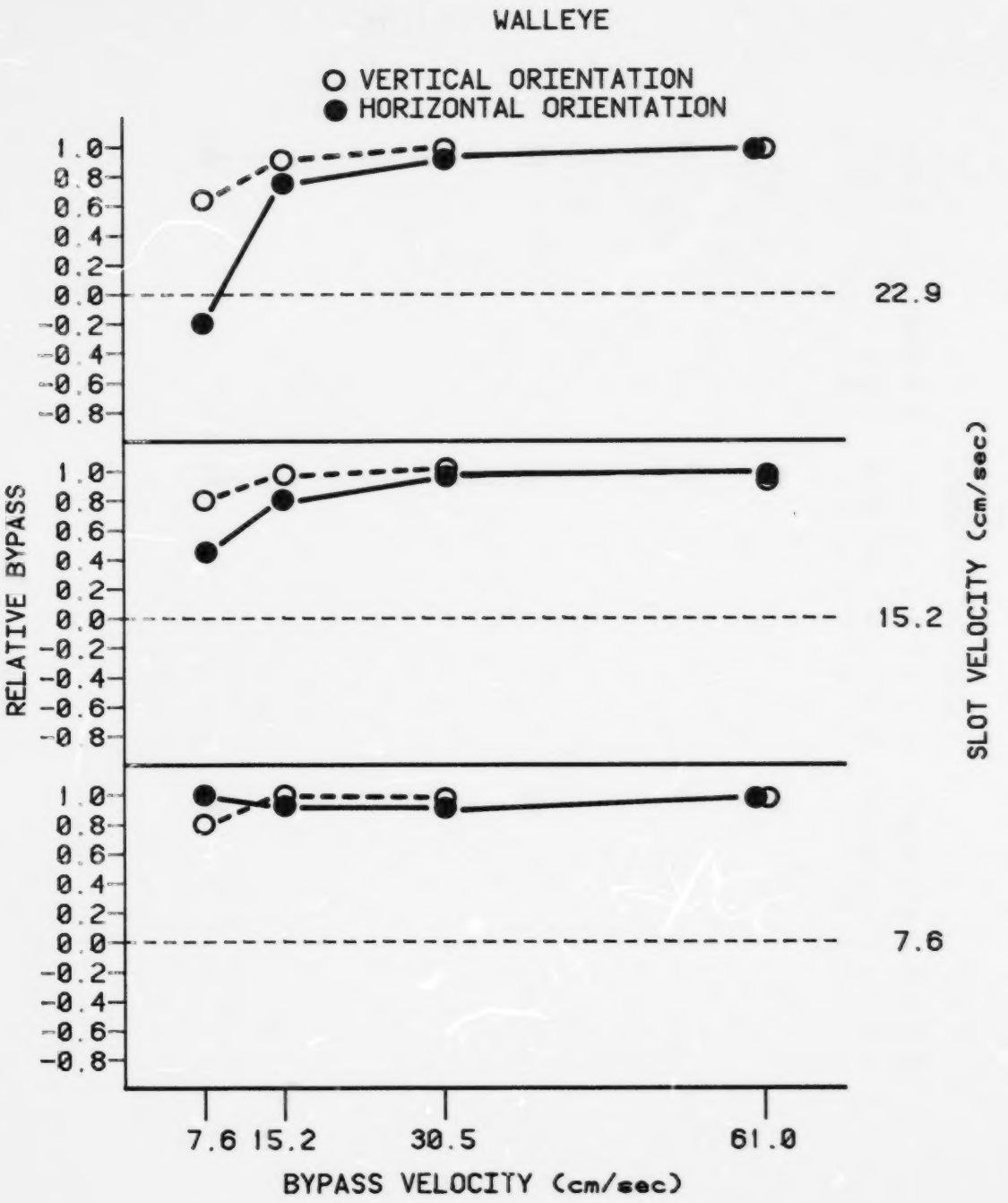


Figure B-17. Results of larval fish screening investigations ("fish avoidance" concept): relationship of relative bypass to bypass and slot velocity for walleye. Slot width of the screen = 1.0 mm.

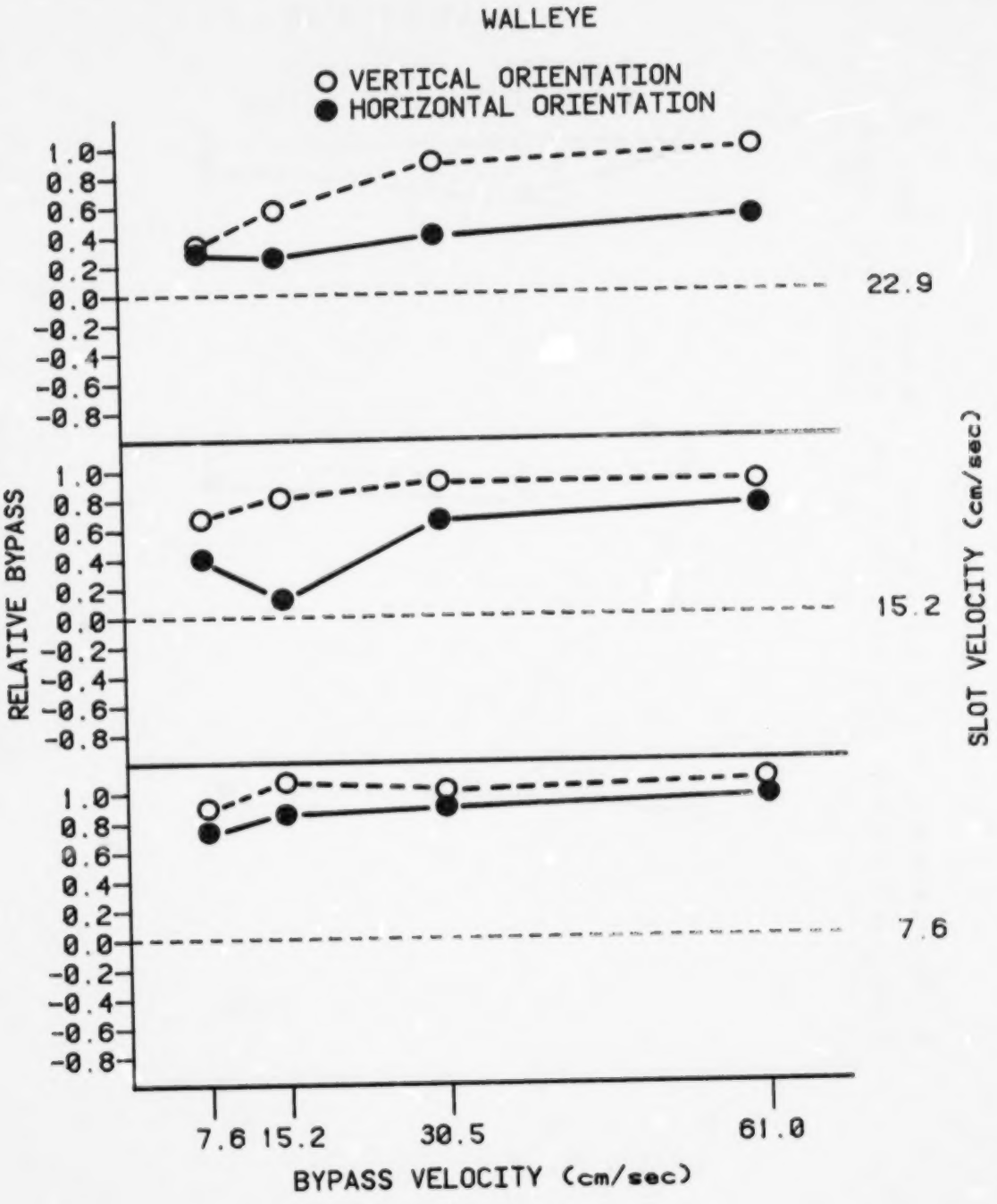


Figure B-18. Results of larval fish screening investigations ("fish avoidance" concept): relationship of relative bypass to bypass and slot velocity for walleye. Slot width of the screen = 2.0 mm.

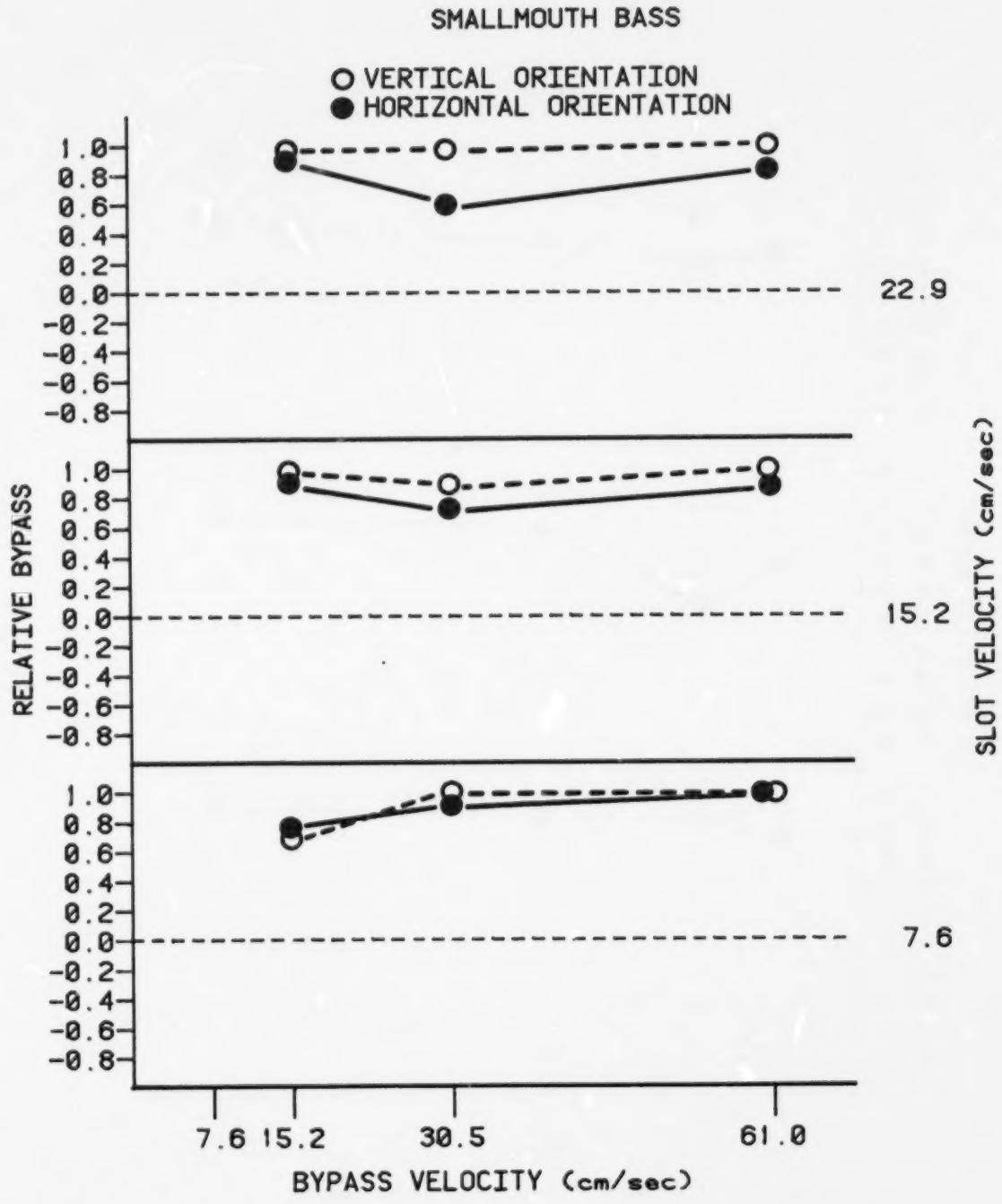


Figure B-19. Results of larval fish screening investigations ("fish avoidance" concept): relationship of relative bypass to bypass and slot velocity for smallmouth bass. Slot width of the screen = 1.0 mm.

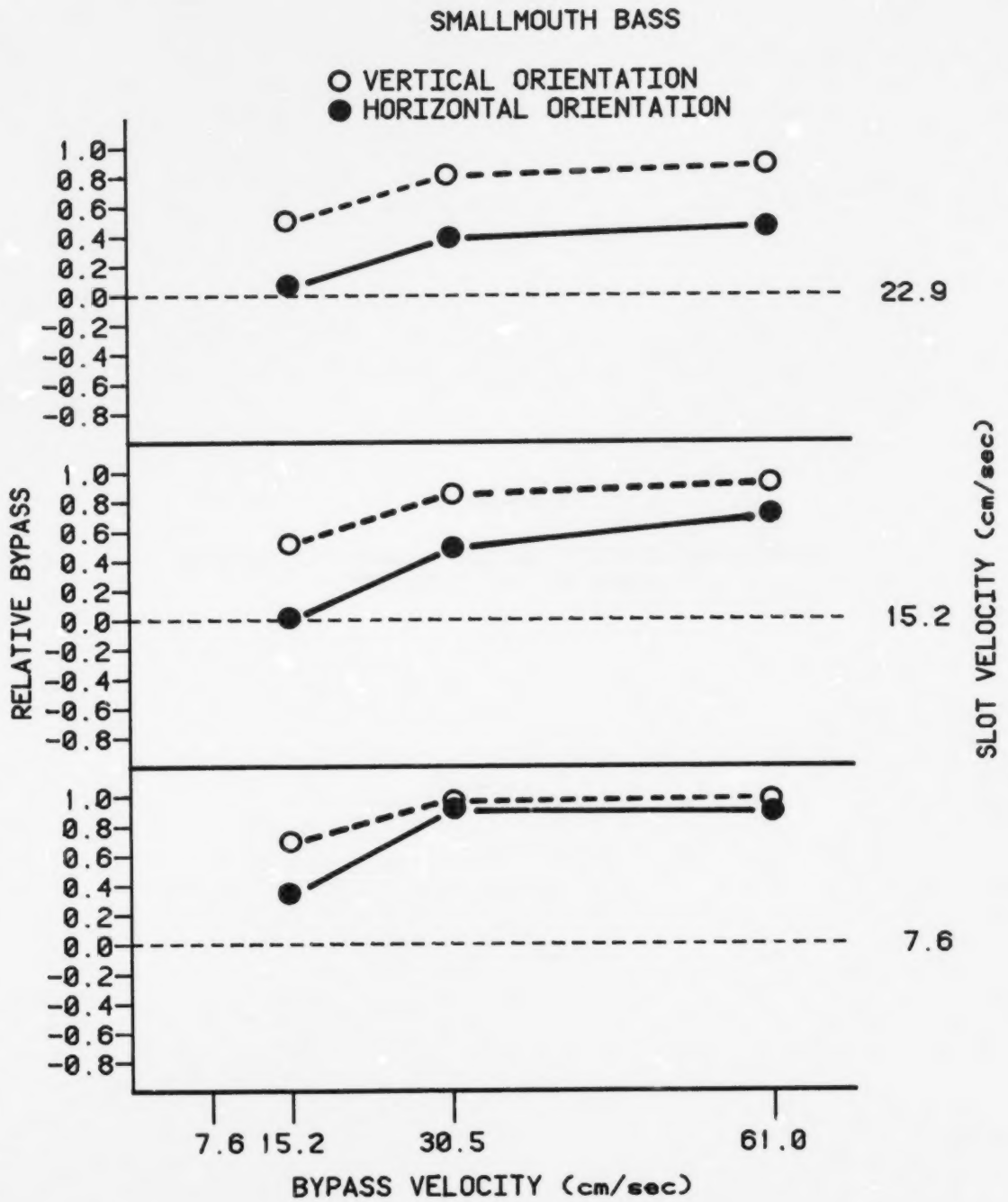


Figure B-20. Results of larval fish screening investigations ("fish avoidance" concept): relationship of relative bypass to bypass and slot velocity for smallmouth bass. Slot width of the screen = 2.0 mm.

APPENDIX C

FORMULA FOR ADJUSTING IMPINGE-RELEASE TEST RESULTS BASED ON CONTROL SURVIVAL

Individual 24-hour survival values were adjusted for observed mortality of the control fish in order to better reflect test-induced mortality. The adjusted values were calculated using the formula:

Adjusted survival =

$$1 - [(D/N) - \bar{M}_c)]$$

where

D = the total number of fish in a sample which died.

N = total number of fish in the sample.

$\bar{M}_c$ = average control mortality (expressed as a proportion).

For example, assume that for one observation with species A:

N = 200 specimens

D = 160 specimens

$\bar{M}_c$ = .45

Unadjusted survival =

$$1 - \frac{D}{N} = 1 - \frac{160}{200} = .20$$

Adjusted survival =

$$1 - [(160/200) - \bar{M}_c] = 1 - [.80 - .45] = .65$$

These values were expressed as a percent in this report.

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APPENDIX D

ANALYSIS OF VARIANCE FOR FOUR
SPECIES SUBJECTED TO IMPINGEMENT,
AIR EXPOSURE, AND SPILLING

TABLE D-1. ANALYSIS OF VARIANCE OF IMPINGEMENT, AIR EXPOSURE, AND SPILLING FOR REDBREAST SUNFISH. ANALYSIS IS BASED ON INITIAL SURVIVAL.

Source	df	Sum of Squares	F-value	Pr > F	R-square
Model	8	6.43704	29.96	0.0001	0.91945
Error	21	0.56394			
Impingement	2	4.76797	88.77	0.0001	
Air Exposure	1	0.10162	3.78	0.0652	
Spill	1	0.03770	1.40	0.2493	
Imp. Dur. x Air Exp.	1	0.01258	0.47	0.5012	
Imp. Dur. x Spill	2	0.04331	0.81	0.4598	
Air Exp. x Spill	1	0.02482	0.92	0.3473	
Corrected Total	29	7.00098			

TABLE D-2. ANALYSIS OF VARIANCE OF IMPINGEMENT, AIR EXPOSURE, AND SPILLING FOR REDBREAST SUNFISH. ANALYSIS IS BASED ON ADJUSTED 24-HOUR SURVIVAL.

Source	df	Sum of Squares	F-value	Pr > F	R-square
Model	8	4.67616	33.97	0.0001	0.92826
Error	21	0.36138			
Impingement	2	3.42956	99.65	0.0001	
Air Exposure	1	0.09723	5.65	0.0270	
Spill	1	0.04341	2.52	0.1271	
Imp. Dur. x Air Exp.	1	0.05132	2.98	0.0989	
Imp. Dur. x Spill	2	0.04617	1.34	0.2830	
Air Exp. x Spill	1	0.06590	3.83	0.0638	
Corrected Total	29	5.03754			

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TABLE D-3. ANALYSIS OF VARIANCE OF IMPINGEMENT, AIR EXPOSURE, AND SPILLING FOR LARGEMOUTH BASS. ANALYSIS IS BASED ON INITIAL SURVIVAL.

Source	df	Sum of Squares	F-value	Pr > F	R-square
Model	9	1.69428	7.90	0.0001	0.73213
Error	26	0.61991			
Impingement	2	0.72110	15.12	0.0001	
Air Exposure	1	0.64616	27.10	0.0001	
Spill	1	0.00067	0.03	0.8685	
Imp. Dur. x Air Exp.	2	0.18027	3.78	0.0362	
Imp. Dur. x Spill	2	0.13884	2.91	0.0723	
Air Exp. x Spill	1	0.00725	0.30	0.5862	
Corrected Total	35	2.31419			

TABLE D-4. ANALYSIS OF VARIANCE OF IMPINGEMENT, AIR EXPOSURE, AND SPILLING FOR LARGEMOUTH BASS. ANALYSIS IS BASED ON ADJUSTED 24-HOUR SURVIVAL.

Source	df	Sum of Squares	F-value	Pr > F	R-square
Model	9	2.13859	6.54	0.0001	0.69369
Error	26	0.94435			
Impingement	2	1.22243	16.84	0.0001	
Air Exposure	1	0.64087	17.64	0.0003	
Spill	1	0.00924	0.25	0.6183	
Imp. Dur. x Air Exp.	2	0.07878	1.08	0.3529	
Imp. Dur. x Spill	2	0.18461	2.54	0.0982	
Air Exp. x Spill	1	0.00167	0.05	0.8320	
Corrected Total	35	3.08295			

TABLE D-5. ANALYSIS OF VARIANCE OF IMPINGEMENT, AIR EXPOSURE, AND SPILLING FOR BIGMOUTH BUFFALO. ANALYSIS IS BASED ON INITIAL SURVIVAL

Source	df	Sum of Squares	F-value	Pr > F	R-square
Model	6	2.27082	38.11	0.0001	0.93079
Error	17	0.16884			
Impingement	1	1.78999	180.23	0.0001	
Air Exposure	1	0.23622	23.78	0.0001	
Spill	1	0.03469	3.49	0.0790	
Imp. Dur. x Air Exp.	1	0.20950	21.09	0.0003	
Imp. Dur. x Spill	1	0.00015	0.02	0.9008	
Air Exp. x Spill	1	0.00025	0.02	0.8763	
Corrected Total	23	2.43966			

TABLE D-6. ANALYSIS OF VARIANCE OF IMPINGEMENT, AIR EXPOSURE, AND SPILLING FOR BIGMOUTH BUFFALO. ANALYSIS IS BASED ON ADJUSTED 24-HOUR SURVIVAL.

Source	df	Sum of Squares	F-value	Pr > F	R-square
Model	6	2.50655	8.51	0.0002	0.75015
Error	17	0.83484			
Impingement	1	2.06539	42.06	0.0001	
Air Exposure	1	0.02346	0.48	0.4987	
Spill	1	0.00469	0.10	0.7610	
Imp. Dur. x Air Exp.	1	0.09768	1.99	0.1765	
Imp. Dur. x Spill	1	0.25786	5.25	0.0350	
Air Exp. x Spill	1	0.05747	1.17	0.2945	
Corrected Total	23	3.34140			

TABLE D-7. ANALYSIS OF VARIANCE OF IMPINGEMENT, AIR EXPOSURE, AND SPILLING FOR WALLEYE. ANALYSIS IS BASED ON INITIAL SURVIVAL.

Source	df	Sum of Squares	F-value	Pr > F	R-square
Model	9	0.97298	1.07	0.4014	0.17017
Error	47	4.74461			
Impingement	2	0.93306	4.62	0.0147	
Air Exposure	1	0.00130	0.01	0.9102	
Spill	1	0.00004	0.00	0.9837	
Imp. Dur. x Air Exp.	2	0.01621	0.08	0.9230	
Imp. Dur. x Spill	2	0.00904	0.04	0.9563	
Air Exp. x Spill	1	0.00047	0.00	0.9454	
Corrected Total	91	5.71759			

TABLE D-8. ANALYSIS OF VARIANCE OF IMPINGEMENT, AIR EXPOSURE, AND SPILLING FOR WALLEYE. ANALYSIS IS BASED ON ADJUSTED 24-HOUR SURVIVAL.

Source	df	Sum of Squares	F-value	Pr > F	R-square
Model	9	2.42175	2.15	0.0341	0.19086
Error	47	2.74357			
Impingement	2	0.65694	6.51	0.0024	
Air Exposure	1	1.07269	3.28	0.0736	
Spill	1	0.11618	0.49	0.4852	
Imp. Dur. x Air Exp.	2	0.46774	0.53	0.5903	
Imp. Dur. x Spill	2	0.05809	0.05	0.9484	
Air Exp. x Spill	1	0.05549	0.84	0.3615	
Corrected Total	56	5.16532			

REFERENCES

Ostle, B. 1963. Statistics in Research. The Iowa State University Press, Ames, Iowa. 585 pp.